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Safety Expenditure and Achievable Benefits

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Abstract:

This project required development of macro level procedures for allocating funds across retrofit safety programmes. The procedures would be used at a capital planning stage to determine how much of a given budget should be allocated to each retrofit to obtain the maximum possible benefits from the expenditures.

Current prioritization methods and results are reviewed, and while the review is not exhaustive, it is a good representation of current practice and new ideas and it does reveal that current procedures are not fully suitable to the decision processes used by MTO.

The report also describes the theoretical development of two complementary prioritization procedures and provides illustrative applications. The first procedure is the net marginal benefit method (the net benefit of retrofitting a site being the difference between the monetary value of the safety benefit and the retrofit cost). Recognizing that safety benefits vary across sites and retrofit programmes, the procedure allows a budget to be allocated to different programmes but ensures that the net marginal benefit is the same for all programmes.

The second procedure is the multi-criteria method. It complements the net marginal benefit method which assumes there is a chosen retrofit measure for each set of sites and/or target accidents. The multi-criteria method addresses how such a treatment or measure can be chosen for any given class or treatment unit.

The appendices provide information useful in the application of the procedures. Appendix A identifies specific retrofits of interest to the MTO and provides summaries for each retrofit, and best estimates of accident reduction factors and of target accidents for MTO roads. Appendix B provides some useful, but limited, data on accident and retrofit costs. Appendix C provides user information for the software to be used in the application of the procedures developed.

Comments: This project carried out under Ontario Joint Transportation Research Project Number 90052.

Key Words: highway safety, decision support tools, benefit-cost, capital allocation, safety review, multi-criteria decisions

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Safety Expenditure and Achievable Benefits

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Executive Summary

It is always difficult to allocate funds for retrofit safety measures across a range of options such as shoulder upgrading, improving the roadway illumination, and installing guiderails.

Which will achieve the greatest benefit for the money spent? If the money is divided between programmes and options, how should that be done? These are important capital allocation decisions for Ministry of Transportation (MTO) staff.

This report discusses computer software developed for prioritizing a safety retrofit programme, and provides typical illustrative applications.

Best estimates of results are provided for accident reduction factors for different highway elements, based on state-of-the-art methods in the literature and original research. MTO-wide implementation costs for various safety retrofit initiatives are indicated.

Also estimated are the safety benefits that will be achieved by implementing a specific retrofit programme, and the total number of potential accidents targetted.

The approach is based on two complementary procedures:

1) the multi-criteria method, and

2) the net marginal benefit measure.

The multi-criteria method can be used to rank possible measures for correcting a variety of safety problems at an individual site. This results in an estimate of total expenditure required for each measure when sites are grouped within a district, or road class, for example.

The net marginal benefit measure is needed because available budgets are rarely sufficient to meet the needs of all options; thus, the net marginal benefit measure can be used to allocate funds amongst the competing measures.

1. Introduction

Current procedures for MTO funding of safety retrofits are believed to be less than optimally efficient. To correct this situation, the terms of reference for this project (Request for Proposal Number 90052) required the development of a procedure for allocating funds across retrofit safety programmes in a manner which results in the maximum possible safety benefit. The tasks outlined in the RFP included:

- identification of both engineering and enforcement programmes where safety benefits arise;
- identification of multiple criteria by which safety benefits can be measured;
- development of a model framework within which these multiple criteria can be analyzed; and
- deriving an appropriate funding allocation procedure to achieve maximum benefits.

Although the project focused on safety retrofits and primarily with the safety repercussions, it should be noted that many retrofits could have favourable or adverse impacts on other factors, primarily traffic efficiency. However, the procedures developed appear to be flexible enough to be extended to account for these other impacts.

In Chapter 2, current prioritization methods used in highway safety analysis are discussed. Chapter 3 deals with the marginal benefit model selected and selected prioritization methodology. The appendices present the assessed state-of-the-art data required for setting of priorities, and the recommended values for accident reduction factors. The appendices also include an assessment of Ontario experience based on the model. Note that references are listed at the end of each chapter.

2. Review of Current Prioritization Methods and Results

A number of relevant sources have been reviewed in order to come to grips with how MTO safety resource spending should be prioritized. While the summary on prioritization methods presented below is not exhaustive, it does appear to be a good representation of current practice as well as new ideas. The summary of resource allocation methods is followed by a section on results obtained from actual prioritization exercises reported in the literature.

2.1 Methods

The summary of possible safety resource allocation methods is in two parts. First, the results of an FHWA initiative about 10 years ago are presented. This is followed by a section on more recent developments.

2.1.1 FHWA Initiative

A useful summary of the FHWA initiative to produce safety resource allocation methods is provided in two reports [2.1, 2.2], the first of which reviews a number of promising procedures for selecting safety improvements to result in the maximum safety benefits per dollar spent. These procedures are grouped into two categories:

1. Weighting methods, including the benefit-cost and cost-effectiveness methods.
2. Mathematical Programming methods, including dynamic and integer programming.

Below, is a brief description of procedures in these categories, followed by a summary of the conclusions in the FHWA reports.

a. Weighting methods

Two main procedures come under this broad class:

Project Development Ranking — ranks projects according to net benefit, cost-effectiveness, rate-of-return or other economic measures and then selects from the list until available funds are depleted. The procedure is simple and popular but is not regarded as effective where there are a number of alternatives at each location or where the priority listing is constantly revised.

Incremental Benefit-to-Cost Ratio — allows a project to be selected if, compared to the next lower-priced alternative, the extra expenditure is justified, i.e., less than the extra benefits. This widely-used procedure is regarded as reducing the impact of very low cost projects in comparison to the benefit-cost ranking method while enhancing consideration of additional improvements based on expected additional benefits. The complexity of manual calculations was regarded at the time of the FHWA report as a disadvantage.

b. Mathematical programming methods

Five methods were considered in the FHWA reports: goal programming, network analysis techniques, linear programming, integer programming, and dynamic programming. The latter three were recommended for consideration in the allocation of highway safety funds and these are summarized below.

Linear programming (LP) — defines a class of problems in which the decision variables are non-negative, the criterion (or objective function) for selecting the best values of the decision variables is a linear function of these variables, and the constraints (e.g., resources) can be expressed as linear equations or inequalities. The LP method is said to be the most widely used method of mathematical programming although it was not common nor easy to employ in the selection of safety measures for specific locations. However, the reports suggested

the LP formulation could possibly be used to allocate safety funds among safety programmes.

Integer Programming — is in essence a linear programming problem in which some or all of the decision variables are restricted to integer values. The FHWA reports state that (at that time) limited progress had been made in the solution of large-scale highway safety problems using this method.

Dynamic Programming — is an optimization technique which transforms a multi-stage decision problem into a series of one-stage decision problems. At the single-stage level, a single project with several alternatives is evaluated while at the multi-stage level, selection is made among several projects, each with several alternatives. At the time of the FHWA reports, two states – Kentucky and Alabama – were actually using this technique and more states were considering it.

In the Alabama application [2.3], the procedure begins with a computer search of accident records over the last several years to provide a list of candidate locations for safety improvement. The data are then summarized and sent to the divisional investigation team where engineers familiar with the location generate possible alternatives to remedy the problem. The engineers are encouraged to add locations to the list that may not yet have had enough accidents to be included, but which they consider potentially hazardous. Investigations at each site are then conducted and standardized forms are sent to the central office for accuracy and consistency checks. The forms are processed by an algorithm which generates cost and benefit data for each alternative at each candidate location.

c. Conclusions from the FHWA initiative

With regard to the choice of safety projects which maximizes total benefits for a fixed budget, the FHWA report [2.1] ranked the possible procedures:

1. Integer Programming
2. Dynamic Programming
3. Incremental Benefit-Cost Ratio
4. Benefit-Cost Ratio

Integer programming is said to always yield the optimal solution and to be insensitive to the form of cost-benefit coefficients (i.e., whether they are monetary or non-monetary). On the other hand, dynamic programming, as applied then in Alabama and Kentucky, will not yield feasible results unless alternative costs are in units of budget increments.

For situations where neither programming method is feasible, the report concludes that benefit-cost ratio analysis should never be used when incremental benefit-cost ratio analysis can be applied. The report suggests that for the safety expenditure allocation problem, incremental B/C gives approximately the same choice of projects as do the programming methods, the main difference being in the choice of marginal projects within the budget. This is not an important shortcoming since safety budgets are often not precisely specified. If, indeed, the budget is precisely fixed, then the shortcoming is particularly important where alternatives, especially those near the budget cut-off level, have large costs relative to the size of the budget and vary considerably in cost and in incremental benefit-cost ratios.

2.1.2 Recent Developments

Four recent papers on methods for allocating safety expenditures are summarized below.

1. Brown *et al.* [2.4] present an update to the dynamic programming used in Alabama [2.3]. They developed a so-called "branch-and-bound" technique to handle larger sets of project data more efficiently and to guarantee optimality.

2. Jiang *et al.* [2.5] argue that neither project ranking nor mathematical programming techniques yield optimal solutions and propose an approach for combining the two techniques for selecting pavement and bridge rehabilitation and replacement projects.

3. McGeehan *et al.* [2.6] evaluated the current road improvement prioritizing system used by the Virginia DOT and sought to develop an alternative method. The system used by the VDOT is a sufficiency rating system that evaluates proposed projects on the basis of points assigned for a number of variables representing cost, safety, traffic intensity and road classification. Values are assigned to a variable based on its estimated significance in the prioritizing decision. Points for each variable are awarded to a project according to its level of deficiency by that criterion with maximum number of points assigned for most serious condition. The sum of points awarded to a project yields a number for comparison with other projects in prioritizing.

   In the new method, each variable is divided into three data ranges representing values that are high (above a threshold), medium (marginal), and low (adequate). All proposed projects are initially sorted into three groups of high, medium, and low as defined by the ranges of a primary variable. The grouped projects are then evaluated using ranges of a second variable. Projects in the high range of the second variable may be elevated to the next highest group. The projects are ranked within the high, medium, and low classification by the ranges of the individual variables as well. In the final prioritized list, the first project in each group would be the most deficient as assessed by all variables.

4. Finally, MTO staff have suggested a model for evaluating the relative efficiency of a set of maintenance patrols [2.7] could be adapted for prioritizing safety projects. The approach is referred to as data envelopment analysis (DEA) [2.8] and is particularly useful where there are similar decision-making units with multiple inputs and outputs and where qualitative factors must be considered. This type of modelling is the basis of one of the approaches presented in Chapter 3, and is not reviewed here.

2.2 Applications of prioritization procedures – Some results

Table 2.1 contains results of a prioritization exercise done by Hall [2.9] and cited in the ITE's *Transportation and Traffic Engineering Handbook* [2.10] as an example of studies that evaluate the safety benefits of various possible improvements.

Hall points out that, generally, the less expensive safety improvements had the highest safety benefit/cost ratio even though the more expensive improvements tended to have higher percent reductions in accidents. Also, those projects with lower safety benefit/cost ratio frequently had benefits other that safety which were not accounted for in the results.

A number of sources recommend cost-effective analysis whereby measures are ranked according to their cost per accident eliminated. This avoids using values for cost per accident that are subject to considerable uncertainty but cannot be made equivalent to the incremental B/C method. Also, if based on total accidents, the method will give unduly low priority to measures that mitigate the severity of accidents rather than reduce their numbers.

The remaining applications employ the cost-effectiveness technique in one way or another. Recently, Benekohal *et al.* [2.11] have found that for 3R projects in Illinois, the B/C ratio for roadside improvements by themselves was very close to that for road improvements as a whole, with both types costing about $30,000 per accident saved. Roadside improvements included treatment of culvert headwalls, removal of trees, poles and posts, and installation or end treatments of guiderails. Road improvements included these roadside improvements along with shoulder and lane widening and upgrading.

The safety cost-effectiveness of design standards was analyzed by the Transportation Research Board [2.12] for 3R projects in the U.S. Tables 2.2 - 2.5 present a sample of results extracted from that report. The costs were originally in 1985 dollars and have been updated to 1991 Canadian dollars assuming a 6% inflation factor.

Table 2.1 *Safety benefits of improvements*

Rank	Improvement	Annual Percent Accident Reduction			Benefit/-
		Accidents	Injuries	Fatalities	Cost Ratio
1	Shoulder widening or improvement	29	20	41	28.83
2	Installation/upgrading of traffic signs	23	33	27	15.03
3	Median barrier	3	6	91	13.73
4	Localized lighting installation	9	9	73	13.24
5	Road edge guiderail	13	15	59	10.97
6	Breakaway signs or lighting supports	35	44	100	7.25
7	Traffic signals, installed or improved	18	32	49	6.36
8	Skid treatment/overlay	17	27	30	6.09
9	Channelization, including left turn bays	23	29	65	3.94
10	Pavement widening, no lanes added	25	38	87	3.68
11	Lanes added, without new median	17	11	31	0.80
12	Widening bridge or other major structures	65	74	33	0.41

Source: "Evaluation of Highway Safety Program Standards," DOT/FHWA, March 1978 [2.9, 2.10]

*Table 2.2 Cost ($1000s) per accident eliminated on flattening horizontal curves by design speed**

Design speed	Design speed AFTER (mph)			
BEFORE (mph)	40	55	60	70
20		25		
30	50	42	57	63
40		114		
45		190		

** Assumes a central angle of 30 degrees and an ADT of 2,000*

*Table 2.3 Cost ($1000s) per accident eliminated on lane and shoulder widening by ADT**

Average Daily Traffic	Cost ($1000s) per accident eliminated
1,000	57
2,000	32
3,000	25
5,000	18
7,000	13

** Assumes rolling terrain, 10-ft lanes and 2-ft shoulders before improvement and 11-ft lanes and 6-ft shoulders after*

*Table 2.4 Cost ($1000s) per accident eliminated on reconstructing crest curves by ADT and design speed before improvement**

Average Daily Traffic	40 mph design speed	35 mph design speed
2,000		88
3,000	107	50
4,000	78	40
5,000	63	32

** Assumes operating speed of 55 mph and a major hazard in the sight-restricted area*

*Table 2.5 Cost ($1000s) per accident eliminated on removing isolated trees and utility poles by ADT**

Average Daily Traffic	Trees	Utility poles
1,000	18	60
2,000	12	40
4,000	7	30
6,000	6	21

** Assumes obstacle is 10 ft from edge of travelled lanes and a 4:1 fill slope behind obstacle*

References (Chapter 2)

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[2.7] Kazakov A., W. Cook and Y. Roll, "Measurement of Highway Maintenance Patrol Efficiency: Model and Factors". *Transportation Research Record* 1216, pp. 39-45, 1989.

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[2.11] Benekohal R. and M. Lee, "Comparison of Safety Effects of Roadside vs. Road Improvements on Two-Lane Rural Highways". Presented at the 70th Annual Meeting, Transportation Research Board, 1991.

[2.12] Transportation Research Board, "Designing Safer Roads", Special Report 214, 1987.

3. Proposed Approaches for Prioritization of Safety Expenditures

3.1 Objectives

The review of current decision tools reveals that a set of better tools should be developed to satisfy the decision processes used by MTO. There is a need for better macro level procedures that would be used at the capital planning stage to determine how much of a given budget should be allocated to each retrofit in order to obtain the maximum possible benefits from the expenditures.

In essence, our primary objective was to seek an end product consisting of:

1. Computer software, and illustrative applications, of a procedure or procedures for prioritizing of safety retrofits.
2. A summary of best estimates for inputs for the software including, as far as possible, estimates of implementation costs, safety benefits, and target accidents for retrofits of interest.

This chapter focuses on progress with respect to the first task (the second is the focus of Appendix A). Two approaches are presented, each defining the problem in a different way.

a. Net marginal benefit method

b. Multi-criteria modelling

These approaches are covered in the next two sections.

3.2 Net marginal benefit method

The problem as envisioned in the proposed approach is to determine the level of expenditure on each type of safety treatment that would maximize the safety benefits obtained for a specified total budget. To illustrate, suppose that the total budget is $5 million. The procedure should be able to estimate, for example, that it is best to allocate $2.0 million for shoulder improvements, $1.0 million for guiderails, $0.5 million for roadside clearance, and $1.5 million for resurfacing. In this example, all the budget is not spent on one type of treatment only for three possible reasons: 1/ there is a limit on the number of sites which require a treatment; 2/ there is a practical limitation on the rate at which treatments could be carried out; and 3/ there are diminishing marginal benefits from expenditure on a specific treatment type after the worst cases are treated. This last reason inspired the proposed approach.

The essence of the proposed approach is in the use of marginal benefit-cost analysis and recent safety estimation theory to estimate the number and costs of projects involving a specific treatment for each of which the net present value (the difference between benefits and costs) exceeds a certain value. The same is done for each treatment type. The net present value threshold is then adjusted until the total cost of all selected projects equals the available budget.

3.2.1 Theory

It is first necessary to define a number of terms. Assuming that for every target accident (i.e., accidents with the same most probable cause) there exists some predominant treatment *t*, let

p_t = ratio of severe to total accidents (severe=injury+fatal), for target accidents,

c_t = cost of treating one site with type *t* treatment, expressed as an annual cost,

b_p = monetary benefit of preventing one property damage accident,

b_s = monetary benefit of preventing one severe accident,

r_{pt} = expected reduction in probability of property damage target accidents after treatment type *t*,

r_{st} = expected reduction in probability of severe target accidents after treatment type *t*,

m_t = expected annual number of target accidents (total) at a site considered for treatment type *t*

B_t = net annual benefit of applying treatment type *t* at a site.

It follows that:

$$B_t = m_t p_t r_{st} b_s + m_t (1 - p_t)\, r_{pt} b_p - c_t \qquad (1)$$

where, $m_t p_t r_{st}$ is the expected reduction in the number of severe accidents after treatment type *t*.

Rearranging terms, it is possible to calculate what value of m_t is required to yield a given net annual benefit:

$$m_t = (B_t + c_t) \,/\, (p_t b_s r_{st} + (1 - p_t)\, b_p r_{pt}) \qquad (2)$$

Assuming that for each treatment the expected reduction in target accidents can be evaluated from accident statistics, Equation 2 could be used to estimate the value of m at the margin. This estimate is done for a given net annual benefit threshold, B^*, and selected treatment type. Treating sites with values of m equal to or larger than the marginal value would have a net annual benefit at least as large as the threshold value. This process can be repeated for each treatment type using the same net annual benefit threshold. If the total budget required does not match what is available then the threshold could be adjusted.

To estimate how many sites have m larger than the marginal value (and the cost of treating them) it is necessary to use some theoretical reasoning applied by others [3.1,3.2]. Analysis, by many authors, of time and cross-sectional data available to them has led to the conclusion that, in a population of sites, the expected number of target accidents m can be modelled as a gamma distribution and that accident occurrence at a specific site obeys the Poisson probability law. It follows from these assumptions that the probability that a site selected at random has x accidents is described by a negative binomial distribution and, therefore, that the mean and variance of the accident count could then be used to estimate the parameters of the gamma distribution for m. The procedure is as follows:

Let: x_i be the count of accidents on site i,

μ be the average of the counts and,

s^2 be the variance of the count.

Then, m is described by a gamma distribution:

$$f(m) = \alpha^{\beta} m^{\beta - 1} e^{-\beta m} / \Gamma(\beta) \tag{3}$$

where, $\Gamma(\beta)$ is the gamma function,

and the parameters α and β of this distribution can be estimated by:

$$\alpha = \mu / (s^2 - \mu) \tag{4}$$

and

$$\beta = \mu^2 / (s^2 - \mu) \tag{5}$$

Then, n, the number of sites with the value of m between m_1 and m_2 can be evaluated as:

$$n = N \int_{m_1}^{m_2} f(m)\, dm \tag{6}$$

where N is the total number of sites.

The number of sites, n^*, with the value of m > m^* where:

$$m^* = (B_t^* + c_t) / (p_t b_s r_{st} + (1 - p_t) b_p r_{pt}) \tag{7}$$

can be evaluated as in Equation 8:

$$n^* = N \int_{m^*}^{\infty} f(m)\, dm \tag{8}$$

The decision problem at hand will then have the following formulation:

Assume that there are k possible treatments, each defined as the best for a specific set of target accidents at a specific group of sites. The sites are assumed to be different for different treatments. With a total budget of A, the problem is to define how many sites should be treated by each treatment to obtain maximum net benefit. This problem can formally be stated as:

max ΣB_t, subject to:

$$\Sigma c_t n_t^* = A$$

The solution, which is well known in economic theory, is to equalize the marginal net benefits, making:

$$B_1 = B_2 = B_3 = \ldots\ldots = B_t = \ldots\ldots$$

An alternative method is to use an accident potential model, if available, to estimate m for each site and the actual distribution of m's in the population of sites of interest. A companion project for the MTO has sought to develop these models for Ontario roads [3.3].

3.2.2 Numerical example # 1

Suppose there are two treatment programmes being considered. The question is for a given budget how much money should be spent on each programme.

Treatment type 1 will reduce severe accidents by 30% ($r_{s1} = 0.3$) and others by 10% ($r_{p1} = 0.1$) at 200 potential sites. The monetary values of these types of accidents are b_s = \$50,000 and b_p = \$2,000, while the cost of treating one site is \$10,000 (an annual cost c_1 of \$1,030 using a 6% discount rate and a 15 year service life). Among target accidents the ratio of severe to total accidents, p_1 is 0.3. From accident counts, $u_1 = 1.049$ and $s_1^2 = 5.983$.

The above values, along with corresponding values for treatment type 2, are summarized in Table 3.1.

Table 3.2 summarizes, for various net annual benefit thresholds, the marginal values of m, the number of sites to be treated and the required budgets. A computer program has been written to use the inputs in Table 3.1 to produce the results in Table 3.2.

The results in Table 3.2 show, for example, that for a budget of approximately \$1 million, \$560,000 should be allocated to programme 1 to treat 56 sites while \$465,000 should be allocated to programme 2 to treat 93 sites.

Table 3.1 Data for budget allocation example # 1

Parameter	Treatment type 1	Treatment type 2
p_t	0.3	0.2
Service life (years)	15	10
Capital cost/site	$10,000	$5,000
c_t	$1,030	$680
b_p	$2,000	$2,000
b_s	$50,000	$50,000
r_{pt}	0.3	0.2
r_{st}	0.1	0.2
μ_{t2}	1.049	2.050
s_t	5.983	3.901
Potential sites	200	300

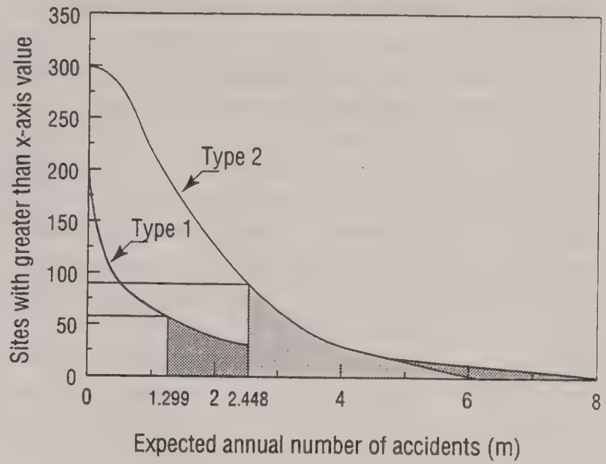

Figure 1 Distribution of target accidents for two treatment types

The results are illustrated graphically in Figure 1. For sites affected by each treatment type, curves have been plotted based on a gamma distribution of *m*'s to indicate the number of sites having m larger than any given value. The shaded regions depict the sites to be treated for an optimum allocation of $1 million. For each graph, in accordance with equation 8, the area of the shaded region represents the expected number of target accidents for the optimum treatment programme.

Figure 2 illustrates, for various budgets, the proportion allocated to each treatment type. Notice that, as the budget increases, the proportion allocated to treatment type 2 is decreasing while that for type 1 is increasing by corresponding amounts. This is an artifact of the larger "tail" for the type 1 distribution evidenced in Figure 1. This result indicates that, contrary to what might be done in practice, when budgets are trimmed, the allocation to various treatment types should not be trimmed in proportion to the reduction in budget.

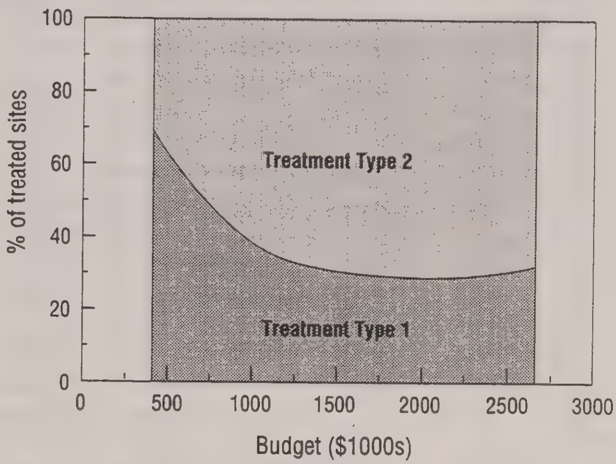

Figure 2 Allocation of budget to two treatment types

Table 3.2 Results from safety expenditure allocation procedure (all costs in $1000's)

Net annual benefit threshold	Sites with $m >$ marginal value								
	m_1 at margin	m_2 at margin	% sites		Number		Cost		Budget required
			1	2	1	2	1	2	
0	0.222	0.293	59	97	118	292	1180	1460	2640
2	0.653	1.155	41	71	82	213	820	1065	2085
5	1.299	2.448	28	31	56	93	560	465	1025
10	2.377	4.603	18	8	35	15	350	75	425

Table 3.3 *Data and results for budget allocation example # 2*

Site	Treatment	Ratio Sev:Total	Accident Mean	Count Variance	Probability of treating	
					$80k Budget	$35k Budget
1	1	0.40	2.9901	6.0400	[0.9945]	[0.9177]
2	1	0.36	1.3226	6.1223	0.5842	0.3658
3	1	0.30	0.5270	1.9431	0.3239	0.1541
4	1	0.36	0.1199	0.1584	0.1002	0.0063
5	1	0.30	0.2972	0.4900	0.2327	0.0416
6	1	0.20	0.5900	1.2200	0.3084	0.0690
7	1	0.40	0.6900	1.1000	[0.6466]	0.2380
8	1	0.25	1.5500	4.5000	[0.6736]	0.3571
9	1	0.50	1.2000	5.2000	[0.6232]	[0.4143]
10	1	0.30	0.3900	0.9000	0.2836	0.0948
11	2	0.30	0.4900	0.9900	0.3128	0.0636
12	2	0.35	1.2200	2.3900	[0.7437]	0.2932
13	2	0.35	1.4400	4.0200	[0.6857]	[0.3382]
14	2	0.40	0.6600	2.2200	0.3911	0.1718
15	2	0.25	0.8800	2.3600	0.4221	0.1298
16	2	0.25	1.4900	2.4300	[0.8372]	0.2379
17	2	0.34	1.8900	6.9900	[0.7110]	[0.4070]
18	2	0.30	3.2200	9.0100	[0.9462]	[0.6871]
19	2	0.24	0.9700	9.9100	0.4085	0.2255
20	2	0.30	1.0700	5.2200	[0.4659]	0.2290
21	2	0.20	1.6900	3.2200	[0.7750]	0.2181
22	2	0.50	0.3300	0.8800	0.3051	0.1164
23	2	0.20	0.4900	1.0100	0.2298	0.0290
24	2	0.28	0.7700	3.2200	0.3521	0.1489
25	2	0.36	1.1800	7.1100	[0.5003]	0.2799

Accident cost = $50,000 (severe); $2,000 (PDO); Discount rate = 6%;
Treatment 1 cost = $10,000/site; Treatment 2 cost = $5,000/site.
Design life = 15 years (treatment 1); = 10 years (treatment 2)

Table 3.4 *Budget allocation summary for example 2*

Treatment #	$80,000 Budget		$35,000 Budget	
	Sites to treat	$Allocated	Sites to treat	$Allocated
1	4	$40,000	2	$20,000
2	8	$40,000	3	$15,000

3.2.3 Extension to the more common resource allocation problem

It is important to note that, in the above illustration of the proposed procedure, *the same site cannot appear in two different treatment programmes.* This places some limitation on the application of the procedure as illustrated – it can be readily applied, for example, for partitioning a budget among different classes of roads in different districts within a jurisdiction.

If it is desired to apply the procedure to allocate a budget among treatments in a single entity, for example, a road class or an entire road jurisdiction, an extension of the procedure developed is required. It would be necessary to treat each site of interest, for example, a 1-km section, as a unit and first decide on a treatment type for each unit. Each unit, according to the theory [3.1, 3.2], has an expected annual number of target accidents, with uncertainty in this value being described by a gamma distribution.

The parameters α and β of this gamma distribution of target accidents could be estimated from, for example, the accident potential models [3.3]. The equations developed earlier are now applied to a specific site rather than to a group of sites. For example, in Equation 8, the value of N is 1 since a single site is being considered, and n^* now represents the probability of $m>m^*$, in effect the probability of that site being treated. The sum of these probabilities over all sites for a specific treatment type would give the expected number of sites for that treatment for the total budget under consideration.

3.2.4 Numerical example # 2

To illustrate the extension of the procedure, consider the data in Table 3.3. Twenty-five sites are considered for two treatment types specified in the example above. For the first 10 sites, engineers have determined that treatment type 1 is better; for the others, type 2 is better. For each site, the procedure estimates the probability of m, the expected number of accidents, being larger than the marginal value for a given budget, in effect, the probability of that site being treated.

These probabilities are summed for each treatment type to indicate in Table 3.4 that, for a budget of $80,000, for example, treatment type 1 should be applied to 4 of the 10 sites considered and type 2 should be applied to 8 of the 15 sites considered. Tables 3.3 and 3.4 show results for both an $80,000 budget and a $35,000 budget; the net annual benefit thresholds for these budgets are $1,000 and $5,000, respectively.

The actual decision on which specific sites to treat might be based on practical as well as theoretical considerations. From a strictly theoretical point of view, it is reasonable to prioritize sites according to the probability of being treated. In this case the sites for which this value is bracketed in Table 3.3 would be considered.

3.2.5 Data requirements

This section discusses data requirements for the model. Since part of the project was to try to summarize available data, in this section we also discuss generally progress made in this respect and provide an overview of what would still be required for the application of the model. This is done under 3 main headings.

a. Estimation of safety expenditures for retrofits

b. Estimation of safety benefits

c. Estimation of other benefits

a. Estimation of safety expenditures for retrofits

To estimate the expenditure on a specific safety retrofit, it is required to estimate unit costs for retrofits and the number of units (e.g., km of road with narrow shoulders or the number of narrow bridges) to be retrofitted under a programme of interest.

Assuming that MTO already has access to in-house information on retrofit costs, we have summarized what is available to us from U.S. sources. With respect to the number of retrofit units of interest, the inventory dataset could be used to obtain such estimates as far as possible. In Appendix A we have attempted to provide province-wide total as far as possible. It should be noted that this dataset cannot provide all the information — data from other MTO sources would be required.

b. Estimation of safety benefits

Four data elements are required:

- The distribution of target accidents across sites
- The expected ratio of severe to total accidents
- Expected reduction in target accidents, by severity
- Accident costs by severity

Distribution of target accidents

Accidents on Ontario roads are classified into groups in accordance with the most probable cause. Each class thus defined becomes the 'target accident' type for a specific countermeasure to mitigate the identified or assumed cause of the accident. It is assumed that the cause of severe and property damage accidents in the same target group is the same and defined by other random events. Assuming that engineering judgement can be used to decide on retrofits, and that there can only be one retrofit for each accident, the highway system can then be split into groups of sections with each section in a group having a common retrofit. The distribution of the number of target accidents over sections in each group is, as indicated earlier, assumed to be a two parameter gamma distribution. These parameters are the desired inputs to the model. As indicated in Section 3.2.1, these parameters could be estimated from the distribution of accident counts for a specified period on sections in a group.

In the extension of the procedure (see numerical example 2, Section 3.2.3.), each group consists, in effect, of one site with a specific retrofit and expected number of target accidents m. The uncertainty in m at a site can also be described by a gamma distribution whose parameters are required inputs in the extended procedure. In this case, these parameters can be estimated from accident potential models [3.3] or from the distribution of accident counts sections that are similar to the one under consideration.

Expected ratio of severe to total accidents

This can be estimated from the breakdown of the target accidents summed over all sites in a group for a specific retrofit type. It is assumed that the same ratio applies to each site in the group.

Expected reduction in target accidents

From the literature review, we have provided in Appendix A best estimates of percent reduction in target accidents (by severity) for each retrofit as far as possible. It was contemplated that we refine these estimates using Ontario accident data. However, the data are cross-sectional and in almost all cases we could not properly infer accident reduction factors from the Ontario accident data available.

The model could be refined in future to recognize uncertainty in the estimates of % accident reduction. The refinements might work as follows: The initial step in the procedure would be to use Monte Carlo simulation to generate an accident reduction factor for each retrofit in accordance with the hypothesized probability distribution that might be shaped from an appraisal of pessimistic, optimistic and most likely values. For example, a beta distribution could be hypothesized based on these values. A set of priorities would be developed using the each of several sets of factors. Projects might then be ranked and budgets allocated by assembling the results of a large number of simulations.

Accident costs by severity

A necessary ingredient for the prioritization of safety retrofits is the use of a monetary equivalent for an accident saved. The estimates found in the literature have a wide range and depend on the assumptions made and when the estimate is made. A summary of our best estimates at this time is given in Appendix B. The most recent MTO-accepted value is presented in Ref. 3.4.

3.3 Multi-criteria model

3.3.1 Introduction

Previously in this report a marginal analysis was presented. For each class of roads there is a probability distribution for the expected number of target accidents. A chosen retrofit measure is assumed for each of these classes, and this measure becomes a major factor in the marginal analysis. The topic addressed in this section is how such a treatment or measure can be chosen for any given class or treatment unit.

For any given class of road different types of accidents occur. Sixteen such types are shown in Table 3.5.

For any particularly type of accident, there may be several different measures that could be applied to relieve the safety hazard.

For illustrative purposes we assume six possible measures are available:

1. Roadway illumination
2. Shoulder widening/upgrading
3. Shoulder guiderail/sideslope flattening
4. Horizontal curve improvements
5. Median improvements
6. Removal/protection of roadside obstacles

The problem is to choose from this set a safety measure for a highway class, such that as many accidents as possible are covered by that measure. Suppose the various accident types occurring in the class are viewed as *criteria* and that the available treatments of measures are ranked in order of applicability (i.e., whether they appropriately address the accidents) for each accident type. Looked at in this manner, the problem of selecting a retrofit measure is a multiple criteria problem where only qualitative data may be available. For example, only an ordinal ranking of the measures may be possible when looking at any given type of accident.

To place the problem in context we first present a brief description of an optimization methodology that can be used to select a retrofit measure.

3.3.2 Multiple criteria methodology

Cook and Kress [3.5] discuss a model for evaluating a set of alternatives (retrofit measures, for example) in terms of a set of ordinal or qualitative criteria. The basic idea is that N alternatives are ranked on an ordinal basis, using L rank positions on each of K ordinal criteria. Furthermore, the K criteria are also ordinally ranked in order of importance. The idea is to derive a set of weights or multipliers w_{kl} corresponding to the alternative being ranked in l^{th} place on criterion k. To illustrate, consider the following simple example in which six retrofit measures are to be evaluated in terms of their impacts on accident reduction. Suppose only three types of accidents are involved (3 criteria). Table 3.6 displays the evaluation for all measures.

Table 3.6 *Ranking of measures by criteria*

Measure	Criteria		
	1	2	3
1	5	1	2
2	3	4	5
3	1	3	4
4	2	3	4
5	2	2	2
6	4	5	1

Table 3.5 *Accident types*

Day-curved-sv-severe	Day-strgt-sv-severe	Ngt-curved-sv-severe	Ngt-strght-sv-severe
Day-curved-sv-PDO	Day-strgt-sv-PDO	Ngt-curved-sv-PDO	Ngt-strght-sv-PDO
Day-curved-mv-severe	Day-strgt-mv-severe	Ngt-curved-mv-severe	Ngt-strght-mv-severe
Day-curved-mv-PDO	Day-strgt-mv-PDO	Ngt-curved-mv-PDO	Ngt-strght-mv-PDO

sv(mv) = single (multi) vehicle   severe = injury+fatal
PDO = property damage   Ngt = night

For example, measure 1 rates 4th as a treatment for type 1 accidents but is the most preferred (ranks in position l = 1) as far as type 2 accidents are concerned.

The problem at hand is to prioritize or rank the six measures from most to least preferred, using the *preference* data provided. At least two complicating issues must be addressed, however, if such a prioritization is to be achieved.

First, the standing or importance of a given measure may be very different on some criteria than on others. Measure #1, for example, ranks 1st on criterion 2, but last (5th) on criterion 1. On the other hand, measure #3 ranks 1st on criterion 1 but 3rd on criterion 2. Which measure should be ranked highest?

This question raises a *second* issue of *criteria importance*. If criterion 1 is much more important than criterion 2, how should this be factored into the analysis? In some cases it may be possible to supply reasonably representative weights, while in other instances it may only be possible to *rank the criteria*. How should an ordinal ranking of criteria be dealt with?

3.3.3 A conventional approach

A crude, but often utilized procedure for obtaining a prioritization of the measures is to begin with a given set of criteria weights $w_1 w_2 w_3$. Using these "known" values, a *weighted rank* is obtained for each alternative. These weighted ranks are then arranged from lowest to highest to achieve the desired prioritization of the measures. Suppose, for example, that the first criterion is given an importance weight of $w_1 = 10$, the second a weight $w_2 = 7$ and the third a weight $w_3 = 5$. The weighted rank R_1 for measure #1 would then be

$$R_1 = 10 \times 5 + 7 \times 1 + 5 \times 2 = 67 \qquad (9)$$

The corresponding value R_2 for measure #2 is

$$R_2 = 10 \times 3 + 7 \times 4 + 5 \times 5 = 83 \qquad (10)$$

For this set of weights, measure #1 comes out at a lower value than #2, meaning that measure #1 should be given a higher priority than #2.[1]

There are two basic operational shortcomings with this crude approach:

a) The method requires that the analyst be able to choose, in some manner and using some scale, a set of weights reflecting the *absolute* importance of the criteria. While in some instances criteria weights may have evolved over time and are a "given" in other cases the weight assignment exercise is ad hoc, hence very much at the *whim* of the decision maker. Even when such assignments are based on the very best advice and information from the relevant players at the time, the scales and values chosen are, in the final analysis, arbitrary. Furthermore, the values chosen often arise from a set of widely varying opinions solicited from experts, executives, etc. In this instance the final "consensus" may be less than satisfactory.

b) A second, and even more disturbing aspect of this methodology is the fact that the rank positions of the measures, which are only intended as *relative* (ordinal scale) priorities, are being treated as if they were *absolute* cardinal (interval scale) values. Ranking measure 3 in 1st place on the first criterion, and measure 4 in 2nd place, for example, is *not* meant to imply that measure 3 should be valued as being *twice as important* as measure 4 relative to this criterion. These rank positions purely express relative priorities, not absolute worths.

3.3.4 A proper evaluation of ordinal data

Therefore, there are generally two sets of "unknowns" in such an environment — the v_l, expressing the importance of the different rank positions $l = 1, \ldots, L$, and the w_k expressing the importance of the K criteria.

With this notation, if a measure ranks in the *ith* category or position on the k^{th} criterion, it will be given a credit of $w_k v_l$ for this criterion. Recall that in the above example, measure #1 received a total credit or value of:

$$R_1 = 5w_1 + 1w_2 + 2w_3 \qquad (11)$$

Thus, for criterion 1, the credit was $5w_1$. The suggestion is that the credit should be $v_5 w_1$, where v_5 and w_1 are to be determined.

To simplify notation, let us use a single variable, with a double subscript, w_{kl}, in place of the product $w_k v_l$. In this case the restrictions specified in (a) and (b) above become:

$$w_{kl} > w_{kl+1} \qquad (12)$$

$$w_{kl} > w_{k+1l'} \qquad (13)$$

for all k and l.

Clearly, there are an infinite number of combinations of weights w_{kl} satisfying these conditions. What is required is a procedure for selecting an "appropriate" set. Whatever this set is, it will immediately dictate the "rating" which each measure will receive, and therefore the final rank ordering of the measures.

---

[1] *Since a rank of 1 means "most important", and 5 means "least important", the measure with the lowest weighted rank will be given the highest priority. Clearly, if we reversed the scale (5 is best, 1 is worst), the opposite interpretations would be given to R_1 and R_2.*

For example, in the case of measure #1 in the above, R_1 is given by:

$$R_1 = w_{15} + w_{21} + w_{32'} \tag{14}$$

since this measure ranked fifth on criterion 1, first on criterion 2 and second on criterion 3. A formal method has been developed for finding appropriate w_{kl} weights, and therefore a set of R_1 ratings. Technical details of this method are reported in other studies, one of which is attached as Appendix C.

In the above description, it is assumed that criteria are ordinally ranked. In some situations, however, criteria weights are supplied. If one were to use, for example, the coefficient of variation figures computed for each accident type in each class as cardinal criteria weights (i.e., weights are given directly), a slightly different variation of the model can be formulated.

In analyzing the data for the seven classes of roads (one class had no data) the ordinal ranking of accident types by total accidents was used. For example, in the case of the U3 class, where only three types occurred (5U3, 7U3 and 13U3) the total numbers of accidents were 35, 40 and 27. Hence, these three types rank 2,1,3 respectively. Appendix C contains the raw data for the eight road classes showing the number of sites n, the mean per site μ, the standard deviation, and the coefficient of variation.

Appendix C shows how the six measures were ranked for each class of road and each accident type in each class. Using the same example of the U3 class, the six measures were rated by the optimization procedure:

m2 - 100	m1 - 55.8
m3 - 77.9	m4 - 51.4
m6 - 60.3	m5 - 51.4

Here, m2 (shoulder widening/upgrading) is a clear winner.

In other cases such as the fifth class of roads R1 (Rural1) the ratings were much closer:

m5 - 100	m4 - 89.4
m2 - 98.4	m6 - 79.7
m3 - 97.4	m1 - 75.4

Here, m5 (median improvements) would be declared the winner, but m2 and m3 are close seconds.

The overall results are:

Class	Recommended Measure
U1	——
U2A	m2 preferred, m3 alternate
U2B	m5, m2, m4 all valid
U3	m2
R1	m5 preferred, m2, m3 alternates
R2A	m2
R2B	m2, m3, m5 all valid
R3	m2 preferred, m5 alternate

To check on these results an alternative set of runs was made using (n) x (coefficient of variation) to rank the accident types. Essentially the same results were obtained.

References (Chapter 3)

[3.1] Hauer E. and B.N. Persaud, "Problem of Identifying Hazardous Locations Using Accident Data", *Transportation Research Record* 975, TRB, Washington, D.C., pp. 36-43, 1984.

[3.2] Jarrett D., Abbess C. and C. Wright, "Bayesian Methods Applied to Road Accident Blackspot Studies: Some Recent Results". In *Proceedings*, Seminar on Short-Term and Areawide Evaluation of Safety Measures, Institute of Safety Research, SWOV, Amsterdam, Netherlands, 1982.

[3.3] Persaud B., "Accident Potential Models for Ontario Road Sections". Draft Final Report for the Ministry of Transportation, Ontario, March 1992.

[3.4] "The Societal Cost of Motor Vehicle Crashes in Ontario," Safety and Regulation Office, MTO, SRO-94-01, 1994.

[3.5] Cook W. and M. Kress, "A multiple criteria decision model with ordinal preference data", *European Journal of Operations Research*, 1991.

Appendix A/

Accident Reduction Factors and Target Accidents

The collection of information capsules in this Appendix applies, to varying extents, for the list of highway improvements identified by the MTO as priorities, but includes other safety related measures as a by-product of the research. The information capsules in this appendix are organized in the following order:

A1. Lane widening and shoulder upgrading
A2. Safety resurfacing
A3. Installation of climbing lanes
A4. Installation of passing lanes
A5. Mitigation of collisions with fixed roadside objects
A6. Installation of roadway illumination
A7. Improvement of horizontal curvature
A8. Measures to reduce intersection accidents
A9. Installation of median barriers
A10. Widening narrow bridges
A11. Treatment of steep sideslopes
A12. Other retrofits

Each capsule contains information in three segments. Below are some notes of relevance to each segment.

Accident Reduction Factors

Provided are best estimates of accident reduction factors obtained from the literature. *In applying these factors to current Ontario conditions due caution is advised* since most of the studies were done for other jurisdictions, many are dated, and several have flaws, sometimes fatal ones, in the analysis. A summary of literature reviewed appears in a recent report for MTO on priorities for safety research (Persaud B.N, "Roadway Safety: A Review of the Ontario Experience and of Relevant Work Elsewhere", Report for MTO, December 1991). The full range of information on accident reduction factors from that report is summarized in Appendix D.

Note that the accident reduction factors should be applied to the expected number of target accidents. The accident count should be used as an estimate of this value only where a site is not identified on the basis of it's accident count. If it is, then accident potential models currently being developed for Ontario should be used.

Ontario Target Accidents

The second section of each capsule contains a brief profile of target accidents on MTO roads. Target accidents counts are on an average annual basis using data for 1988 and 1989 on MTO roads. Details of the data base are given in the report referenced above. The information is provided in two forms, listed below along with some relevant notes.

i. Province-wide totals

Readers are cautioned against making improper inferences from the cross-sectional data provided in the province-wide totals. In particular, differences in accident counts between two groups should not be attributed to any specific difference between the groups. The data in these profiles are not intended to be used for inferring accident reduction factors. Rather, they are intended to provide an indication of target accident counts to which accident reduction factors estimated from other sources should be applied.

Target accidents are the basis for applying accident reduction factors and are not to be taken as indicative that these accidents result from the absence of the retrofit. This is because of limitations in studies that form the basis of our estimates for accident reduction factors. In some cases, available accident reduction factors are on the basis of total accidents even though only a small subset are target accidents and an even smaller portion are correctable by a specific retrofit.

ii. Distribution

The information – parameters for a gamma distribution of target accidents is for use in applying the Net Marginal Benefit methodology outlined in Chapter 3. The basic data is the mean and variance of target accidents over sites of interest. In most cases this is straightforward since the sites are known from the inventory file and the accidents on these sites are known form the accident file. In some cases, however, e.g., illumination, unilluminated sections are not identified in the inventory file; from the accident file the count of accidents on each section *having target accidents* is known. This knowledge is used, along with theory of the truncated negative binomial distribution, to *estimate* the number of sections with 0 target accidents and ultimately the gamma distribution parameters. Indication is given when this special estimation was used.

Retrofit Cost

Again, due caution is advised. This information is provided for completeness and is often based on crude estimates and assumptions. In addition they only apply to the average of conditions that would vary widely across Ontario.

Notes:

1. The literature base is not comprehensive. In particular, some papers available during the time that this report was being assembled may not have been cited.
2. The capsule information in this Appendix for each retrofit type was extracted largely from more detailed summaries contained in an earlier report for MTO - Persaud, B.N. "Roadway Safety - A Review of the Ontario Experience and of Relevant Work Elsewhere", MTO Report PAV-92-02, 1992. As such there are some omissions. Readers interested in more detailed information should consult that report or the original sources cited after each capsule.
3. Confidence Rating Scale:

   Rate 3: Usable with minor cautions, e.g., relevance of data, extrapolation of results.

   Rate 2: Usable with extreme caution, e.g., possible study biases, lack of sufficient for higher rating, applicability to differing conditions, sample size.

   Rate 1: Not relevant or usable because, e.g., obvious flaws/biases in analysis, date of study.
4. Abbreviations used:

   C/S = Cross-section type study

   B/A = Before and After study

   Dec. = Decrease in accidents

   Inc. = Increase in accidents

   Var. = Various accident reduction factors for different conditions

   Accident types:
   FO - Fixed Object; **SS** - Side Swipe;
   RE - Rear-end; **LT** - Left Turn;
   RA - Right Angle; **OD** - Opposite Direction

A1/ Lane Widening and Shoulder Upgrading

Table A1 *Summary of accident reduction factors for lane widening and shoulder upgrading*

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
			Tot	Fat	Inj	PDO	Type	Rating		
77.1	B/A	230 km	Dec.				All	1	Widen 2-lane to 12-ft lanes	Compounded by effects of other improvements.
82.1	B/A 2 yr/2 yr	30 sects. 214 miles	Dec.				All	1	Add full paved shldr.; 2-lane	
88.1	C/S regression models	4951 miles 2-lane	16 29 40				FO/OD FO/OD FO/OD	2 2 2	2-ft sh. widen 4-ft sh. widen 6-ft sh. widen	Other extensive accident reduction factors given based on regression model; problem is that model does not include all factors. Caution when extrapolating.
			Var.				FO/OD	2	various/chart	

Accident reduction factors: (based on Table A1)

The following accident reduction factors are extracted from Zegeer's nomographs [Ref. 88.1, Table D1] for a few typical MTO project types. On the basis of the other studies reviewed it is estimated that optimistic factors would be 50% larger than those in the nomographs while most likely values would be 20% larger

% reduction in target accidents, lane and shoulder widening on 2-lane roads						
Lanes		Shoulders[1]		Pessimistic	Most Likely	Optimistic
Existing	Future	Existing	Future			
≤ 9 ft	11 ft	0 ft	0 ft	23%	27%	34%
≤ 9 ft	11 ft	0 ft	6 ft	50%	60%	75%
≤ 9 ft	11 ft	0 ft	4 ft	40%	48%	60%
11 ft	11 ft	0 ft	6 ft	40%	48%	60%
11 ft	11 ft	0 ft	4 ft	29%	35%	43%

[1] *Same factors apply for paved and unpaved*

Ontario target accidents

a. Province-wide totals:

These are for run-off road and opposite direction accidents on 2-lane roads. The population of 2-lane roads is identified from the inventory file.

Target accidents for lane/shoulder upgrading						
Lanes Existing	Shoulders Existing	Total km	Fatal	Injury	PDO	Total
$\leq$ 9 ft	0 ft	335	1	9	11	21
11 ft	0 ft	7430	52	658	661	1371

b. Distribution:

The expected annual number of <u>total</u> accidents on each type of road is assumed to be gamma-distributed with parameters shown in the table below. Assume that severity is distributed in the proportions indicated in the table above.

Lanes	Roads	Gamma Parameters	
Existing	Existing	α	β
$\leq$ 9 ft	0 ft	5.0419	0.32681
11 ft	0 ft	2.1711	0.36985

Retrofit costs

The following costs are extracted from U.S. data. Ontario-specific data would improve the quality of the estimates, but the U.S. costs could be used as a first cut.

Lanes		Shoulders		Cost/km, \$1000s	
Existing	Future	Existing	Future	Paved shldr.	Unpaved shldr.
$\leq$ 9 ft	11 ft	0 ft	0 ft	75	
$\leq$ 9 ft	11 ft	0 ft	6 ft	150	105
$\leq$ 9 ft	11 ft	0 ft	4 ft	125	95
11 ft	11 ft	0 ft	6 ft	75	30
11 ft	11 ft	0 ft	4 ft	50	20

References: Table A1

[77.1] Rinde E.A., "Accident rates vs. shoulder width". FHWA and California DOT report CA-DOT-TR-3147-1-77-01, 1977.

[82.1] Rogness R.O., Fambro D.B. and D.S. Turner, "Before-after accident analysis for two shoulder upgrading alternatives". *Transportation Research Record* 855, 1982.

[88.1] Zegeer C.V., Reinfurt D.W., Hummer J., Herf L. and W. Hunter, "Safety effects of cross-section design for two-lane roads". *Transportation Research Record* 1195, 1988.

[91.1] Goldstine R., "Influence of Road Width on Accident Rates by Traffic Volume". Preprint, Paper No. 910030, Transportation Research Board Annual Meeting, January 1991.

A2/ Safety Resurfacing

Table A2 *Summary of accident reduction factors for safety resurfacing*

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
		-	Tot	Fat	Inj	PDO	Type	Rating		
66.1	B/A	5 states	12				Wet	1	2-lane rural wet acc. problem	Low conf. rating because of sparse information.
74.1	B/A 1 yr/1 yr	4 sects. 79 km	-100				All	2	Narrow 2-lane	Possibly a result of high quality surface on road with poor geometrics.
78.1	B/A control 1 yr/1 yr	142 sects. 15 states	2 8 -15				All Wet Dry	3	Includes other improvements	Also compounded by effects of speed limit reduction and 1974 energy crisis.
80.1	B/A	59 sects.	-2				All	3	2-lane section	Subset of data in 78.1 but uses omits sections where other improve-ments done.
81.1	B/A	24 sects. 51 km	-12				All		2-lane rural	Skid resistance improve-ment projects.
85.1	B/A control 3 yr total	14 sects. 289 km	20 13				All All	3	1 yr after 2 yrs after	Only Ontario study?

Accident reduction factors: (based on Table A2)

Accident reduction factors for safety resurfacing			
	% Accident reduction in wet pavement accidents		
	Fatal + Injury	PDO	Total
Pessimistic	0	0	0
Most Likely	10	15	15
Optimistic	15	20	20

Ontario target accidents

The inventory data identifies those sections currently with a relatively low pavement condition rating (PCR). Note that the threshold value used (PCR = 75) might be conservative in some cases. Accidents in all weather conditions are included. Therefore, what is provided below might be regarded as an upper bound on target accidents.

System-wide

The breakdown of annual accidents (in all weather conditions) on sections with PCR < 75 is as follows:

	km	Severe	PDO	Total	Severe/Total
Multi-lane freeways	509	148	4428	4576	0.032
Other multi-lane	116	23	1016	1039	0.022
2-lane primary	5522	349	6954	7303	0.048
2-lane secondary	494	21	70	91	0.231

Distribution

The expected number of TOTAL accidents per year on 1-km sections of the above roads are assumed be gamma-distributed with estimates of the parameters alpha and beta as shown in the table below.

Road class	Gamma Parameters	
	α	β
Multi-lane freeways	0.00508	0.45649
Other multi-lane	0.00487	0.43613
2-lane primary	0.27555	0.36443
2-lane secondary	0.50670	0.00936

Retrofit costs

For broad estimation purposes, resurfacing costs can be estimated at $60,000 per km per lane. More detailed costs can, of course, be obtained from in-house MTO sources.

References: Table A2

[66.1] Jorgensen and Associates and Westat Research Analysts, "Evaluation of Criteria for Safety Improvements on the Highway". Report PB-173-822 prepared for the Office of Highway Safety, U.S. Bureau of Public Roads, Gaithersburg, MD, October 1966.

[74.1] Arkansas State Highway Department, "Comparison of Accident Rates Before and After Rehabilitation of Narrow Pavements". October 1974.

[78.1] Blackburn, R.R. *et al.*, "Effectiveness of Alternative Skid Reduction Measures, Vols. I and II". Report nos. FHWA-RD-79-22 and -23, Federal Highway Administration, Washington, D.C., November 1978.

[80.1] Federal Highway Administration, "RRR Alternative Evaluations for Non-Interstate Rural Arterial and Collector Highway Systems". Washington, D.C., March 1980.

[81.1] Tignor S. and J.A. Lindley, "Accident Rates on Two-Lane Rural Highways Before and After Resurfacing". *Public Roads*, Vol. 44 No. 4, March 1981, pp.137-139.

[85.1] Sabo P. and E. Hauer, "The Safety Effect of Resurfacing Rural Highways". *Proceedings*, Canadian District Annual Conference, Institute of Transportation Engineers, Hamilton, June 1985.

A3/ Installation of Climbing Lanes

Table A3 Summary of accident reduction factors for climbing lanes

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
		-	Tot	Fat	Inj	PDO	Type	Rating		
68.1	?		13				All	1		Low conf. rating due to lack of information.
88.1	C/S B/A control	 12 sites	31 26				All All	1 1.5	Swedish sites 1972-77	Conf. rating could be improved with more info.

Accident reduction factors: (based on Tables A3, A4)

The following values were deduced from examination of both climbing and passing lane studies. The factors are to be applied to all accidents at potential locations.

	Fatal & Injury Accidents	All Accidents
Optimistic	20%	15%
Most Likely	15%	10%
Pessimistic	10%	5%

Ontario target accidents

The inventory provides no information on road grade. The best that could be done at this time is to use the accident file to get a feel for target accidents. Even so, the closest approximation is for 2-lane non-intersection accidents on hills. As such, the target accident data below might be regarded as an upper bound.

System-wide

Target accidents for climbing lane installation				
	Fatal	Injury	PDO	Total
All accidents	26	491	368	885
Approaching/rear-end	8	61	20	89

Distribution (Truncated — See Notes on Page 14)

The expected number of accidents per year on 0.5 km sections of roads with hills are assumed be gamma-distributed with estimates of the parameters $\alpha = 0.00609$ and $\beta = 0.00476$. These parameters are based on an *estimate* of total number of sections of 9758. Assume that severity is distributed in the proportions indicated in the table above.

Retrofit costs

For broad estimation purposes, climbing lane installation costs can be estimated at $200,000 per km based on U.S. cost figures. More detailed costs can, of course, be obtained from MTO sources.

References: Table A3

[68.1] Voorhees A., "Crawling Lane Study: An Economic Evaluation", Department of Environment, Great Britain, 1968.

[88.1] ADI, "Evaluation of Passing Lane Safety", Prepared for Transport Canada, September 1988.

A4/ Installation of Passing Lanes

Table A4 *Summary of accident reduction factors for passing lanes*

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
			Tot	Fat	Inj	PDO	Type	Rating		
77.1	B/A	19 projs.	26				All	2	California	Conf. rating could be improved with more info.
85.1	C/S 1-5 yrs data	13 sites 13 matches	38	29			All	1.5		Usual difficulties with cross-section studies.
85.2	B/A	22 sites	9	22			All	2.5		
91.1	C/S				20 42		All All	1 1	5-10,000 ADT Higher ADT	Usual difficulties with cross-section studies.

Accident reduction factors (based on Table A4)

On the basis of the studies reviewed the following accident reduction factors are recommended for locations where passing lanes are installed.

	Fatal & Injury Accidents	All Accidents
Optimistic	30%	25%
Most Likely	25%	20%
Pessimistic	15%	10%

Note: *These reductions apply to the total expected number of accidents at a potential passing lane location.*

Ontario target accidents

The inventory provides no information to identify potential passing lane sections. The best that could be done at this time is to use the accident file to get a feel for target accidents. Even so, the closest approximation is for 2-lane non-intersection accidents excluding those on hills that might be targets for climbing lane installation. As such, the target accident data below might be regarded as an upper bound.

Systemwide

The Table below summarizes information necessary for obtaining approximate estimates of target accidents.

Target accidents for passing lane installation				
	Fatal	Injury	PDO	Total
All accidents	181	3942	7956	11799
Approaching/rear-end	80	915	966	1971

Distribution

The expected number of total accidents of the above types on 2-km sections are gamma-distributed with parameters shown below. Assume that severity is distributed in the proportions indicated in the table above.

Accident type	Gamma Parameters	
	α	β
All accidents	0.49839	0.15767
Approaching/rear-end	1.38851	0.22109

Retrofit costs

For broad estimation purposes, passing lane installation costs can be estimated at $200,000 per km based on U.S. cost figures. More detailed costs can, of course, be obtained from MTO sources.

References: Table A4

[77.1] Rinde E., "Accident Rates vs. Shoulder Width", California Department of Transportation, Sacramento, California, 1977)

[85.1] Harwood D.W., A. St. John, and D.L. Warren, "Operational and Safety Effectiveness of Passing Lanes on Two Lane Highways". *Transportation Research Record* 1026, TRB 1985.

[85.2] Harwood D.W. and A. St. John, "Passing Lanes and Other Operational Improvements on Two-Lane Highways". Federal Highway Administration Report FHWA/RD-85/028, 1985.

[91.1] Taylor W.C. and M. Jain, "Warrants for Passing Lanes". *Transportation Research Record* 1303, 1991.

A5/ Mitigation of Fixed Roadside Object Accidents
(Utility and sign poles, fences, culverts, bridge supports, ditches and trees)

Table A5 *Summary of accident reduction factors for measures for fixed object accidents*

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
			Tot	Fat	Inj	PDO	Type	Rating		
84.1	C/S Regression	35 rigid 16 b'way poles		80			Pole	1	High speed	Applies to injury reduction capacity of br'way poles. Usual difficulties with cross-section studies.
				Various			Pole	1.5	Pole type, seat belt use, speed	
84.1 (Same as above)	C/S Regression	?		80			FO	1.5	High speed	Applies to injury reduction capacity of protective barriers (guiderail) for fixed objects. Same comment on study type.
				Various			FO	1.5	Seat belt use, speed	
84.2	C/S Regression	9583 pole accs. on 1534 sects		Various			Pole	2	ADT, pole type, offset, density, speed, curvature	Models used to predict effect of changing conditions. Same comments about cross-section studies.
90.1	C/S Regression	1080 sects 7 states	Various, e.g., 35% reduct. per m offset for poles; 22% for trees				FO	2	ADT, terrain, object type & density, lane width, offset	Models for various fixed object types used to predict effect of changing conditions. Same comments as above.

Several accident types are lumped into one category because of the relatively small number of accidents of each type.

Accident reduction factors (based on Table A5)

Based on estimates of accident reduction factors for each type of fixed object and on the relative numbers of each type of accident the following accident reduction factors can be assumed for crude estimation purposes.

	Fatal/Injury	PDO
Optimistic	50%	+10%
Most Likely	40%	0
Pessimistic	20%	-10%

Ontario target accidents

Systemwide

Accidents in which the objects listed are the first object struck are identified in the Table below. The inventory file does not provide information on fixed objects on road sections. On the other hand, the accident file used does not provide information on objects struck after the first one. Thus in terms of absolute number of strikes, ditches might be over-represented in the accident data used.

	Fatals	Injury	PDO	Total
Pole (utility or tower)	2	67	132	201
Pole (sign or marker)	2	66	238	306
Fence or noise barrier	0	15	52	67
Culvert	1	18	14	33
Bridge support	0	13	45	58
Ditch	8	258	308	574
Tree, shrub or stump	0	25	28	53
Total	13	462	817	1292

Distribution (Truncated — See Notes on Page 14)

On one-km section of roads the expected annual number of total target accidents is gamma-distributed with parameters $\alpha = 1.49852$ and $\beta = 0.00886$, based on an *estimate* of 20,640 sections. Assume that severity is distributed in the proportions indicated in the table above.

Retrofit costs

Assuming that retrofits are made in proportion to the number of accidents in the Table above, a weighted cost per km of mitigating accidents to fixed roadside objects can be taken as $50,000.

References: Table A5

[84.1] Kurucz C.N., "An Analysis of the Injury Reduction Capabilities of Breakaway Light Standards and Various Guardrails", *Accident Analysis and Prevention*, Volume 16, No. 2, pp.105-114, 1984.

[84.2] Zegeer C. and M.R. Parker, Jr., "Effect of Traffic Features on Utility Pole Accidents", *Transportation Research Record* 970, TRB 1984.

[90.1] Zegeer C, Stewart R., Reinfurt D., Council F., Neuman T., Hamilton E., Miller T. and W. Hunter, "Cost Effective Geometric Improvements for Safety Upgrading of Horizontal Curves", Volume 1, Final Report. University of North Carolina Highway Safety Research Center. May 1990.

A6/ Installation of Roadway Illumination

Table A6 Summary of accident reduction factors for roadway illumination

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
		-	Tot	Fat	Inj	PDO	Type	Rating		
71.1	C/S	203 miles 21000 accs	40	52			Night	2	Urban freeways Many cities	Usual difficulties with cross-section studies.
72.1	B/A 2 yrs/1 yr	5.3 miles	57 31	75 61			Ni/Dy Ratio	2	12 ft median 33 ft median	Urban freeways 6-lane. Small sample size.
76.1	B/A 1 yr/1 yr	130 lamps	25				Night	1.5	"Major route"	Implied from effect of turning off lamps to save energy.

Accident reduction factors: (based on Table A6)

	All Accidents	Fatal & Injury accidents
Optimistic:	57%	75%
Pessimistic:	20%	30%
Most Likely:	30%	40%

Note: *Apply to the total expected number of night accidents*

Ontario target Accidents

The inventory file does not provide information at this time on whether a section has artificial illumination. For the accident file it was possible to obtain data on accidents which occurred during darkness on sections without illumination since this information is coded.

Systemwide

1988 Accidents during darkness on sections without illumination				
	Fatal	Injury	PDO	Total
Freeways	41	1178	2331	3550
Rural Primary	65	1346	2631	4042
Other Primary	2	104	163	269
Rural Secondary	5	116	222	343

Distribution (Truncated — See Notes on Page 14)

The expected number of total accidents of the above types on 1-km sections are gamma-distributed with parameters shown below. Assume that severity is distributed in the proportions indicated in the table above.

Road class	Estimated no. of sections	Gamma Parameters	
		α	β
Freeways	5941	0.1943	0.1161
Rural Primary	15328	1.0204	0.2691
Other Primary	510	0.3722	0.1961
Rural Secondary	2857	3.1171	0.3738

References: Table A6

[71.1] Box P.C., "Relationship between illumination and Freeway Accidents". *Illuminating Engineering*, May/June 1971, pp. 365-393.

[72.1] Box P.C., "Freeway Accidents and Illumination", TRB 416, 1972.

[76.1] Box P.C., "Effect of lighting reduction on an urban major route". *Traffic Engineering*, October 1976, pp. 26-27.

A7/ Horizontal Curve Improvements
(Minor improvements such as widening and curve warning and delineation)

Table A7 *Summary of accident reduction factors for horizontal curve improvements*

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
			Tot	Fat	Inj	PDO	Type	Rating		
83.1	C/S Regression 3 yrs data	3357 sects. 2-lane	Var.				Curve	2	Depends on road width, curve length, ADT, curvature	Estimated, e.g., reduction of .0336 per mil veh. mi. per degree change in curvature. Problems with cross-sect study.
87.1	C/S Regression 3 yrs data	282 sects. 815 accs. 2-lane	Var.				Curve	2	Depends on lane width, ADT, curvature	Usual difficulties with cross-section studies.
90.1	C/S Regression	3427 sects. 2-lane	Var.				Curve	2	Depends on road width, ADT, curve length, curvature	Usual difficulties with cross-section studies. Indicate up to 80% reduction.
90.2	C/S Regression	155 curves	Var.				Curve	2	Depends on ADT, curvature	Fewer variables than others but usual difficulties with cross-section studies.

Accident reduction factors (based on Table A7)

Since these cover a variety of improvements, they should be used for crude estimation purposes only.

Optimistic	40%
Most likely	25%
Pessimistic	10%

Ontario target accidents

Inventory file does not provide information on curvature. The accident file provides data on whether an accident occurred on curved alignment but does not specify degree of curvature and in particular whether the curvature is substandard. As such, the target accidents shown below — non-intersection ones on curved alignment — can be regarded as an upper bound.

Systemwide

1988 accident data indicate that 3.5% of all non-intersection accidents on 2-lane MTO roads occur on curved horizontal alignment. If fatal accidents alone are considered the comparable figure is 21%, comprised largely of single vehicle accidents. For multi-lane roads, comparable figures are 2.4% for all accidents and 15% for fatal accidents. The target accident breakdown is shown below.

Target accidents for horizontal curvature improvements

	Fatal	Injury	PDO	Total
All accidents	67	455	353	875
Single vehicle only	47	294	237	578
2-lane total	44	238	163	445
2-lane single vehicle	29	176	127	332
Multi-lane total	23	217	190	430
Multi-lane single vehicle	18	118	110	246

Distribution (Truncated — See Notes on Page 14)

The expected number of total accidents of the above types on 1-km sections are gamma-distributed with parameters shown below. Assume that severity is distributed in the proportions indicated in the table above.

Road class	Estimated no. of sections	Gamma Parameters	
		α	β
Freeways	1788	0.005464	0.007968
Other Multi-lane	231	0.19922	0.003727
2-lane rural primary	8744	0.81654	0.21380
other 2-lane primary	117	0.31791	0.65769
2-lane secondary rural	6036	1.3801	0.01036
other 2-lane secondary	76	2.0618	0.11309

Retrofit cost

Assume approximately $50,000 per km.

References: Table A7

[83.1] Glennon J.C., Neuman T.R., and J.E. Leisch, "Safety and Operational Considerations for Design of Rural Highway Curves", Report FHWA-RD-86/035. FHWA, U.S. Dept. of Transportation, August 1983.

[87.1] Lam R. and E.M. Choueiri, "Accident Rates on Curves as Influenced by Highway Design Elements Based on Investigations in the State of New York", TRB Annual Meeting 1987.

[90.1] Zegeer C, Stewart R., Reinfurt D., Council F., Neuman T., Hamilton E., Miller T. and W. Hunter, "Cost Effective Geometric Improvements for Safety Upgrading of Horizontal Curves", Volume 1, Final Report. University of North Carolina Highway Safety Research Center. May 1990.

[90.2] Lin F.B., "Flattening Horizontal Curves on Two Lane Rural Highways", *ASCE J. Transp. Eng.* Mar/Apr 90.

A8/ Measures to Reduce Intersection Accidents

Table A8.1 *Summary of accident reduction factors for left turn channelization*

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
			Tot	Fat	Inj	PDO	Type	Rating		
66.1	?	?	-6					1	Add turn lanes no signals at 4-legged rural.	Accident reductions reported for other conditions. Few details of study available at writing
			-47					1	Add turn lanes & sig. at Tee.	(thus low conf. rating).
68.1	B/A	53 ints.	34				All	2	Overall	Also found that raised channelization works best in
		13 ints.	17				All	1.5	Signals no LT phase	urban area. Warrants based mainly on accident count recommended. Unclear whether
		38 ints.	48				All	2	Unsignalized	study sites were selected on basis of accident count.
		38 total	32				All	2	Unsig. painted	If so, then benefits overstated.
			64				All	2	Unsig. raised	
68.2	B/A with control	15 ints. on 1 mile	38	31			All	2.5	Signalized painted	Most of reduction is in LT and RE accs. Unclear if selection bias exists.
78.1	?	?	70 60 65 30 50 50 36 15				All	1	uns,urb,raised uns,rur,raised uns,sub,raised uns,urb,paint uns,rur,paint uns,sub,paint sig,LT phase sig,no LT ph.	Details unavailable; thus low conf. rating.
82.1	B/A 3 yr/3 yr	8	55				All	2	Arterials Hamilton, Ont.	Includes other reconstruction.
84.1	C/S 3 yrs	90 rural uncontrolled	60				RE/SS	1	unpaved shldrs	Usual difficulties with
			10				RE/SS		paved shldrs	cross-section studies.
			0				LT		All types	
89.1	C/S	46 urban 4-lane	59 88 73 52 66 86 -68				RE RE SS SS LT LT RA	1	sig, no LT ph. uncontrolled sig, no LT ph. uncontrolled sig, no LT ph. uncontrolled uncontrolled	Usual difficulties with cross-section studies.

Table A8.2 *Summary of accident reduction factors for traffic signal installation*

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
			Tot	Fat	Inj	PDO	Type	Rating		
59.1	B/A	39 signals	-23	20			All	2	Mostly rural Varied designs	Somewhat dated. Too much variety in conditions.
68.1	B/A 2 yr/2 yr	30 signals	-16	-26			All	2	Rural	Good overall, but analysis of how safety effect varies is flawed.
70.1	B/A 1 yr/1 yr	19 signals	-7	-21			All	2	Rural, low vol, high speed	Small sample size. Suspect some regression to mean.
71.1	B/A 1 yr/1 yr	13 signals	8	-27			All	2	Rural Ontario	Would be more valuable if more details provided.
75.1	B/A 1-2 yr pers.	30 signals	-24	+18			All	2	Virginia DOT	
	B/A	33 signals	-8					1	Calif. city	
82.1	control B/A 3-4 yr pers.	39 signals	7	–11			All	2.5	NY DOT	A useful study.
82.2	control B/A 2-3 yr pers.	31 signals	2	-6			All	2.5	Urban	A useful study.

Table A8.3 *Summary of accident reduction factors for intersection lighting*

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
			Tot	Fat	Inj	PDO	Type	Rating		
76.1	c/s compare night/day	263 light 182 unlit (data-yrs)	45				Night Rate	1		Also, 26% decrease in day rate— indicating that intersections are different in aspects other than lighting.
			22				Night Total			
76.2	b/a; 3 yrs bef. and aft	47 int.	52				Night Rate	2.5	at-grade stop controlled	Does not adjust for 12.7% decrease in day rate; also possible overestimation due to bias by selection of high accident sites for installing lighting.
76.3	Possibly b/a Periods, size, not available	Warranted	72				Night Rate	2	Roads under California DOT jurisdiction	Overestimation for warranted group suspected since accident count was likely part of warrant.
		Unwarranted	38							

Accident reduction factors (based on Table A8)

i. Measures for turning accidents — left-turn lanes

% reduction in turning accidents after left-turn channelization		
	Signalized	Unsignalized
Optimistic	35%	60%
Most likely	20%	50%
Pessimistic	10%	30%

Note: *Use same factors for both severe and PDO accidents*

ii. Measures for right-angle accidents — signals

	% reduction in target accidents	
	Right-angle	Rear-end
Optimistic	75	- 40
Most Likely	50	- 60
Pessimistic	35	- 100

iii. Intersection illumination

	All Accidents
Optimistic	50%
Pessimistic	20%
Most Likely	40%

Note: *Apply to the total expected number of night accidents*

Ontario target accidents

The inventory does not describe intersections. From the accident file, however, we are able identify whether an accident occurs at an intersection, the type of control at that intersection, whether the accident occurred in darkness and whether it involved a turning vehicle (no separation for type of turn). This analysis was the basis for the target accidents shown in the tables below.

Systemwide

i. Accidents occurring at intersections which involved turning vehicles.

Target accidents for measures to reduce turning accidents				
	Fatal	Injury	PDO	Total
Signal-controlled	6	584	881	1471
Stop-controlled	7	594	1040	1641
All intersections	13	1178	1921	3012

ii. Accidents which occurred at intersections and were or the rear-end or right angle type.

Target accidents for traffic signal control		
	Right angle	Rear-end
Fatal	7	0
Injury	215	591
PDO	231	664
Total	453	1255

iii. Accidents which occurred at intersections during darkness where, according to the accident report, there is no artificial illumination.

Target accidents for intersection illumination	
	No. of Accidents
Fatal accidents	16
Non-fatal injury accidents	700
Property damage only	1000

These occur at 1260 intersections

Distribution (Truncated — See Notes on Page 14)

Assume that the expected annual number of accidents at intersections is gamma-distributed with parameters given in the table below. Assume that severity is distributed in the proportions indicated in the tables above.

Accident type	Gamma Parameters	
	α	β
Turning accidents	0.37036	0.09250
Rear-end accidents	0.35294	0.07833
Right-angle accidents	1.0194	0.22122
Total accidents	0.16626	0.05713
Night accidents (unilluminated)	0.98668	0.16013

Retrofit cost

Assume, based on U.S costs, approximately $30,000 per intersection for geometric improvements such as left-turn lanes and $100,000 per intersection for installation of traffic signals. For this report, we have no information on cost of illuminating intersections.

References: Table A8.1

[66.1] Jorgenson and Associates and Westat Research Analysts, "Evaluation of Criteria for Safety Improvements of the Highway". Report PB-173-822, Office of Highway Safety, U.S. Bureau of Public Roads, 1966.

[68.1] Hammer C.G. and T.N. Tamburri, "Evaluation of Minor Improvements, Part 5, Left Turn Channelization", California Division of Highways, May 1968.

[68.2] Terry D.S. and A.L. Kassan, "Effect of Channelization on Accidents", *Traffic Engineering*, Dec. 1968.

[78.1] Lee J., "Developing Left-turn guidelines for priority Intersections in the State of Kansas". University of Kansas Centre for Research, Report FHWA-KS-78-1, 1978.

[82.1] Main M., "Four Underutilized Collision Reduction Measures", Roads and Transportation Association of Canada Monograph, September 1982.

[84.1] McCoy P.T., Hoppe W. and D. Dvorak, "Cost effectiveness evaluation of turning lanes on uncontrolled approaches to rural intersections". Nebraska Department of Roads, Report No. TRP-02-15-84, October 1984.

[89.1] McCoy P.T. and M.S. Malone, "Safety Effects of Left Turn Lanes on Four Lane Roadways", Paper No. 880035, Transportation Research Board 68th Annual Meeting, Washington, D.C., January 1989.

References: Table A8.2

[59.1] Solomon D., "Traffic Signals and Accidents in Michigan", *Public Roads* 30, pp. 234-237, 1959.

[68.1] Schoene G.W. and H.L. Michael, "Effects of a Change in Traffic Control Device on Intersection Accidents", Purdue University, Engineering Reprint CE 237, 1968.

[70.1] Cribbins P. and J. Walton, "Traffic Signals and Overhead Flashers at Rural Intersections: Their Effectiveness in Reducing Accidents", *Transportation Research Record* 325, pp. 1-14, 1970.

[71.1] Leckie D, "Traffic Signalization - Before and After Accident Analysis", Department of Highways, Ontario, 1971.

[75.1] King G.F. and R Goldblatt, Relationship of Accident Patterns to Type of Intersection Control", *Transportation Research Record* 540, pp. 1-12, 1975.

[82.1] New York State DOT, "Effect of Signalization", Traffic and Safety Division, 1982.

[82.1] Short M.S., Woelfe G.A. and C. Chang, "Effects of Traffic Signal Installation on Accidents", *Accident Analysis and Prevention* 14, pp. 135-145, 1982.

References: Table A8.3

[76.1] M.E. Lipinski and R.H. Wortman, "Effect of Illumination on Rural At-grade Intersection Accidents" *Transportation Research Record* 611. Transportation Research Board, Washington, D.C., 1976.

[76.2] F. W. Walker and S.E. Roberts, "Influence of Lighting on Accident Frequency at Intersections," *Transportation Research Record* 562, Transportation Research Board, Washington, D.C., 1976.

[76.3] "Motor Vehicle Accidents in Relation to Geometric and Traffic Features of Highway Intersections", U.S. Department of Transportation, Federal Highway Administration Report No. FHWA-RD-76-129, 1976.

A9/ Installation of Median Barriers

Table A9 Summary of accident reduction factors for installing median barriers

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
		-	Tot	Fat	Inj	PDO	Type	Rating		
66.1	B/A	26.6 miles	-32	-18			Med'n	1	Cable Barriers	Study dated. Possibly not relevant in light of design advances since.
		27.6 miles	-20	-30			Med'n	1	Beam Barriers	

Accident reduction factors (based on Table A9)

(Assumed to apply to median encroachment accidents. Factors have a high variability.)

	% reduction in target accidents		
	Fatal	Injury	PDO
Median width <12 ft, double faced beam rail	75%	2%	-28%
Median width <12 ft, concrete barrier	90%	10%	-10%
Median width >12 ft double faced beam rail	85%	5%	-30%
Median width >12 ft, concrete barrier	85%	Not available	

Ontario target accidents

The inventory file provides basic information on median type and width for divided highways, but there are difficulties identifying target accidents. For the information below target accidents are identified as those having the median identified in the accident location field. Thus, the accident numbers shown might be regarded as a lower bound on target accidents. In future it may be prudent to also look for opposite direction accidents on divided highways.

<u>Province-wide</u>

	Total km	Avg. ADT	Fatal	Injury	PDO
All roads (< 22 m)	1,653	35,950	2	41	61
All roads (≥ 22m)	433	16,501	0	12	16
Roads with barriers	440	99,305	0	13	25
No barriers (< 22m)	1,222	27,837	2	28	36
No barriers (≥ 22m)	431	16,501	0	12	16

Distribution

Parameters of the gamma distributions for total accidents are given below. Assume that severe accidents are distributed in proportions indicated above.

Road class	Gamma Parameters	
	α	β
All roads (< 22m)	5.5063	0.6006
All roads (≥ 22m)	8.9588	0.8242
Roads with barriers	7.6165	0.8419
No barriers (< 22m)	6.3423	0.6516
No barriers (≥ 22m)	8.9588	0.8242

Retrofit cost

Median barrier installation can be estimated to cost approximately $70,000 per km.

References: Table A9

[66.1] Johnson R., "Effectiveness of median barriers". *Highway Research Record* 105, 1966.

A10/ Widening and Other Improvements to Narrow Bridges

Table A10 *Summary of accident reduction factors for narrow bridge improvements*

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
			Tot	Fat	Inj	PDO	Type	Rating		
61.1	B/A 353 accs. over 12 yrs.	65 bridges	Inc.				Bridge	1	Approach widened to 24 ft	Study dated, thus of limited relevance.
		7 bridges	Dec.				Bridge	1	App. & bridge to 30 ft wide	
76.1	B/A	24 accs.	90				Bridge	2	Side of bridge	Treatment consists mainly of W-section approach and bridge rail. Limited sample size.
			66				Bridge	2	End/Approach	
84.1	C/S Regression 4 yrs data	1087 bridges 2849 accs.	Var.				Bridge	1.5	Depends on relative width	Models used to imply effect of changing width, but does not account for other factors. Usual problem with cross-section study.

Accident reduction factors (based on Table A10)

Installing bridge and approach rail

	Optimistic	Most Likely	Pessimistic
Accidents to side of bridge	90%	60%	45%
Accidents to bridge end or approach	70%	45%	35%

Widening existing narrow bridge

	Fatal	Injury	PDO
Optimistic	45%	45%	30%
Most likely	36%	35%	25%
Pessimistic	25%	25%	15%

Ontario target accidents

On MTO roads, about 1% of all accidents (2% of fatals) occur at overpasses and bridges. It is unclear how many more accidents occur in the vicinity of bridges or how many occur at narrow bridges. Further, the inventory file used provides no information on bridges.

Data need

For narrow bridge treatments to be part of a resource allocation procedure it would be necessary to obtain a feel for how many narrow bridges there are province wide and the average number of target accidents per bridge and per unit of traffic volume. Even rough approximations of these quantities require substantial effort.

References: Table A10

[61.1] Gunnerson, H.E., "Iowa Narrow Bridge Accident Study". *Highway Research Abstracts*, Vol. 31, No. 7, July 1961.

[76.1] Woods D.L. *et al.*, "Remedial Safety Treatment of Narrow Bridges". *Traffic Engineering*, March 1976.

[84.1] Turner D.S., "Prediction of Bridge Accident Rates". *ASCE Journal of Transportation Engineering*, Vol. 110, No. 1, January 1984.

A11/ Treatment of Steep Sideslopes

Table A11 *Summary of accident reduction factors for treatment of steep sideslopes*

Year/Ref	Method	Size	% Reduction				Acc.	Conf.	Conditions	Comments
			Tot	Fat	Inj	PDO	Type	Rating		
88.1	C/S Regression	595 sects 1777 miles	Var.				SV	2	Depends on ADT, side-slope, lane/shoulder width, roadside recovery dist.	Model used to imply the effect of changing slope. Difficulty is that not all factors are accounted for in the model.

Accident reduction factors (based on Table A11)

Table A11 provides limited information, but since this topic is the basis for a recent MTO project, further guidance should be obtained from the project report: "Benefit-Cost Analysis of Flatter Embankment Slopes", Queen's University (MTO report PAV-92-07, R&D).

Ontario target accidents

Information on side slope is not available in the inventory or accident files. However, an upper bound on target accidents was obtained by looking at run-off-road accidents. Note that these also constitute part of the target group for lane and shoulder widening.

<u>Province-wide</u>

Target accidents for side-slope improvement (Run-off road accidents)

	Total km	Avg. ADT	Fatal	Injury	PDO
All roads	20,395	16,105	100	2,409	2,693
Roads with shoulder < 1.8m	10,089	5,069	14	505	502
Roads with gravel shoulder < 1.8 m	9,200	2,669	11	427	417
2-lane roads with shoulder < 1.8 m	9,899	2,280	14	473	460
2-lane roads with gravel shoulder < 1.8 m	9,100	2,214	11	416	404
2-lane roads with lanes < 3.0 m	132	308	1	14	7
2-lane roads with lanes < 3 m and shoulder < 1.8 m	117	309	1	13	6

<u>Distribution</u>

The parameters of the gamma distributions for total accidents are given below. Assume that severe accidents are distributed in proportions indicated above.

Road class	Gamma Parameters	
	α	β
All roads	1.22179	0.29757
Roads with shoulder < 1.8 m	2.25530	0.22616
Roads with gravel shoulder < 1.8 m	2.12740	0.20373
2-lane roads with shoulder < 1.8 m	1.38941	0.16190
2-lane roads with gravel shoulder < 1.8 m	1.55102	0.16294
2-lane roads with lanes < 3.0 m	3.39223	0.58304
2-lane roads with lanes < 3 m, shoulder < 1.8 m	2.75465	0.48327

Retrofit cost

For guidance, see report for recent MTO project: "Benefit Cost Analysis of Flatter Embankment Slopes". Department of Civil Engineering, Queen's University.

References: Table A11

[88.1] Zegeer C. *et al.* "Accident Effects of Sideslopes and other Roadside Features on Two-lane Roads". TRR 1195, 1988.

A12/ Other Retrofits

This segment captures other retrofits that are of interest to MTO but for which there is often little or no information on safety repercussions and, in some cases, target accidents. These other retrofits are identified below followed by a brief report on progress made. References are provided for these capsules since these elements were not covered in the recent review of roadway safety knowledge (Persaud B.N, "Roadway Safety: A Review of the Ontario Experience and of Relevant Work Elsewhere", MTO report PAV-92-02, R&D branch).

A12.1 Correction of pavement drop-offs (edge ruts)

A12.2 Safety improvements to gore areas

A12.3 Mitigation of collisions with rock cuts

A12.4 Guiderail delineation

A12.5 Anti-glare screens

A12.1 Correction of pavement drop-offs (edge ruts)

The following accident reduction factors are reported for paved shoulders in reference [A12.1.1] which reports them with a high index of variability. They are taken from an unpublished report and no details of the data are given. It is assumed that these factors apply to total accidents.

% reduction in accidents for shoulder paving to correct pavement drop-offs				
	Fatal	Injury	PDO	Total
Sections	–5	0	5	5
Horizontal Curves	15	15	15	15
Intersections	10	10	10	10

A12.2 Safety improvements to gore areas

There seems to be little before and after information on retrofitting gore areas with impact attenuators. The most extensive study seems to be a 1973 study by Viner *et al.* [A12.2.1] cited in an FHWA report [A12.2.2] which analyzed accidents to attenuators to determine those which might have resulted in death or serious injury — those in which a rigid object would have been struck at > 25 mph. It was determined that half of these accidents were reduced to property damage only. In the FHWA report the accident reduction factor for impact attenuators is given as a 50% reduction in fatal and injury accidents. The report also gives the ratio of fatal-injury to total accidents with various attenuator types. The range is from 9% for the Fibco type to 45% for Tor-Shok.

In terms of target accidents, the Ontario data currently available does not appear to have any codes that would flag such accidents.

A12.3 Mitigation of collisions with rock cuts

Accident tabulations in Appendix B of the recent roadway safety review show the following number of accidents in 1988 on MTO roads in which a rock face is the first object struck:

Fatal	1
Injury	48
PDO	49

It is possible that rock faces are more of a problem than these figures indicate since there might be several accidents in which the rock face is struck subsequent to the first impact.

Currently, little is known about the safety repercussions of measures to mitigate these accidents. An MTO-sponsored research project is currently investigating this issue.

A12.4/ Guiderail delineation

This is the subject of a current MTO request for research proposals. In the meantime, we can provide the following information.

Perhaps the most useful guidance on guiderail delineation issues is provided in a recent FHWA report [A12.4.1]. With respect to safety aspects, the report stated that analysis performed on guiderail accidents "did not produce any conclusive information about the underlying causes of nighttime accidents involving guiderail". The reason given was the difficulty of isolating guiderail accidents from the data due to accident reporting methods.

By contrast, a preliminary analysis of accident data on MTO roads provides some useful insights. Table A12.1 below indicates that in the 2-year period 1988-1989, there were 125 <u>reportable</u> accidents involving vehicles striking guiderail on curves at night. It is our understanding that guiderail damage is caused by these accidents and many more non-reportable or non-reported ones; thus, these numbers are a lower bound on the number of target accidents for guiderail delineation.

Table A12.1 *1988-89 accidents involving vehicles and guiderail on curves at night*

	Fatal		Injury		PDO		Total	
	2-lane	Multi-lane	2-lane	Multi-lane	2-lane	Multi-lane	2-lane	Multi-lane
Cable	1	1	8	2	17	9	25	11
Concrete	0	0	6	2	1	6	7	8
Steel	1	4	2	20	1	45	4	66
Total	3	5	16	24	19	60	36	89

The numbers in Tables A12.2 are more revealing. They indicate that the relative risk of vehicles striking guiderail on curves is substantially greater on curved sections at night. Although the data are cross-sectional and due caution is required in making inferences, the clear indication is that guiderail delineation on curves could have a considerable safety impact.

Table A12.2 *Night/day ratio of accidents involving vehicles striking guiderail (Based on 1988-89 accidents. Parentheses indicate # of night accidents.)*

	Curved section	Straight sections
2-lane	9.0 (36)	0.7 (305)
Multi-lane	3.2 (89)	0.7 (980)

A12.5 Anti-glare screens

This, too, is the subject of a recent MTO request for research proposals. Over 12 years ago, an NCHRP report [A12.5.1] concluded that "although some feel that the potential value of glare screen lies in reducing night accidents, the data from studies in several states do not support this view". A cursory examination of some relevant literature and of MTO accident data confirms this conclusion and indicates that little has changed since to alter it. The proposed research appears to be timely.

References (Capsule 12)

[A12.1.1] Garner G., "Accidents at median crossovers". *Highway Research Record* 312, pp. 55-63, 1970.

[A12.2.1] Viner J. and C. Boyer, "Accident Experience with Impact Attenuation Devices", Federal Highway Administration Report No. FHWA-RD-73-71, April 1973.

[A12.2.2] McFarland *et al.*, "Assessment of the Techniques for the Cost-Effectiveness of Highway Accident Countermeasures", Federal Highway Administration Report No. FHWA-RD-79-53, 1979.

[A12.4.1] Campi, J.S., "Guiderail Delineation". FHWA Report 87-006-7751, prepared by the New Jersey Department of Transportation, 1990.

[A12.5.1] Transportation Research Board, "Glare Screen Guidelines". NCHRP *Synthesis of Highway Practice* # 66, 1979.

Appendix B/ Information on Costs

This appendix is divided into 2 parts: information on monetary value of accidents, and preliminary data on cost of retrofits that MTO might consider.

i. Monetary Value of Accidents

A necessary ingredient for the prioritization of safety retrofits is the use of a monetary equivalent for an accident saved. The range of estimates found in the literature is wide and depends on the assumptions made in addition to the point in time at which an estimate is made. The table below is a sample of some relatively recent estimates, converted to 1991 dollars using an inflation factor of 6% per year. The last line in the table presents the current MTO values used, which are based on a willingness-to-pay analysis.

Source/Reference	Monetary equivalent of accidents saved ($1,000)		
	Fatal	Injury	PDO
NHTSA 1983 [1]	561	16	2
NSC 1983 [2]	364	19	2
Kragh [3]	1913	14	3
OPP 1991 [4]	403	13	3
MTO 1994 [5]	6133	27	6

1 1983 estimates by the National Highway Traffic Safety Administration
2 1984 estimate by the U.S. National Safety Council
3 Kragh et al., "Accident Costs for Highway Safety Decision Making", Public Roads, Vol. 50, No. 1, June 1986
4 Toronto Star, April 25, 1991, Page 1.
5 "The Societal Cost of Motor Vehicle Crashes in Ontario" SRO-94-01, MTO, 1994.

ii. Cost of Safety Retrofits

In any resource allocation procedure the cost of potential improvements is a vital ingredient. Presented below is a summary of costs derived from MTO and other sources. These can be used to supplement in-house estimates in future applications of the procedures presented.

Retrofit costs — non-MTO sources

The information on the following pages are derived largely from TRB's Special Report 214. Conversions are made to 1991 dollars and, where possible, to SI units.

Illustrative costs for flattening sideslopes on fill sections

Construction cost per km ($ 1,000) for one side of highway					
Original Slope	New Slope	Height 1 m	1.5 m	2 m	2.5 m
1:1	2:1	12	25	43	63
	3:1	23	49	84	125
	4:1	34	73	125	186
2:1	3:1	14	26	43	64
	4:1	23	49	84	126
	6:1	46	97	167	249
3:1	4:1	13	26	45	65
	6:1	35	74	127	188

Resurfacing and incremental widening costs-two lane rural highways	
Type of project	Added cost per km ($1000)
Resurface two 3.5 m lanes	114
Widen lanes 2.5 m in each direction	52
Widen paved shoulders 0.5 m in each direction	25
Widen unpaved shoulders 0.5 m in each direction	12

Unit costs for selected roadside object removal and protection strategies		
Type of Action	Unit Cost (1991 $)	Remarks
Guiderail		
Removal	8.12/m	
	14.07/m	
Installation	54.12/m	
	84.62/m	Additional $733 for each end treatment.
	49.20/m	
	104.11/m	
Replacement	123.00/m	Includes removal of old rail and some bridge rail.
Bridge rail end treatment	9450.00/bridge 7920.00/bridge	New rail costs same as guiderail.
Tree removal	357.00/tree	Based on removal of 184 trees.
	396.00/tree	
	330.00/tree	
	990.00/tree	Less than 100 non-marketable trees.
	127.50/tree	More than 100 non-marketable trees.
Utility pole rRelocation		
Wood/telephone	607.50/pole	Rural
Wood/low power	2235.00/pole	Rural
Wood/high power	3990.00/pole	Rural
Nonwood	3060.00/pole	Rural
All types	2377.50/pole	
	3870.00/pole	
Sign relocation	292.50/sign	"small" sizes
Breakaway sign inst.	315.00/sign	
Impact attenuator installation	6600.00/unit	Sand-filled type

Illustrative costs for lengthening crest vertical curves to increase stopping sight distance					
	Initial Curve		Improved Curve		
Difference in Grades (%)	Length (m)	AASHTO Design Speed (km/h)	Length (m)	AASHTO Design Speed (km/h)	Project Cost ($1000)
4	61	56	120	69	102
4	61	56	244	85	204
4	122	69	244	85	189
4	122	69	305	91	248
4	183	77	244	85	164
6	61	50	244	75	236
6	61	50	427	90	422
6	122	61	244	75	216
8	183	62	305	74	317
8	183	62	549	88	599

Representative costs of intersection improvement	
Type of Project	Construction Costs ($1991)
Widening and new channelization	150,000 – 225,000
Installation of new traffic signals	90,000 – 150,000
Reconstruction of one approach	75,000 – 115,000
Construction of new turning lanes	15,000 – 30,000
Realignment of curb	15,000

Widening of existing bridges

In SR 214, the following cost model was proposed:

$$C = 100 + 1100/W$$

where C = unit cost of bridge widening in $ per square feet and W is the width to be added (in feet). Converting to W in metres and C to 1991 dollars the revised model is:

$$C = 69 + 225/W$$

Retrofit costs — MTO sources

The costs below are derived from a few MTO sources including an April 1990 report from the Estimating Office titled "Highway Construction Costs". The costs are reported in 1989 dollars.

New structures

Costs include an estimated 12% for engineering and sundry.

Type	$ Cost per m^2 of deck		
	Substructure	Superstructure	Total
Post-tensioned concrete slab	200	900	1,100
Precast concrete beams	400	700	1,100
Steel I-beams	400	900	1,300
Steel box beams	600	900	1,500
Concrete rigid frame	500	1,200	1,700

Major widening

Costs are for widening from 2 to 4 lanes and are reported for 3 regions with a comment that they are subject to a high degree of variance. Costs include an estimated 25% for engineering, materials and sundry.

Region	Cost/km ($1000)
S. West	900
Central	1,200
Northern	1,100

Reconstruction

Costs are applicable to 2-lane highways only and are reported for all regions with comments that there are substantial variances within regions depending on the degree of reconstruction and the extent of grading. Costs include an estimated 25% for engineering, materials and sundry.

Region	Cost/km ($1000)
S. West	215
Central	260
Eastern	270
Northern	265
N. West	240
Provincial	250

Resurfacing (and Grading)

Costs are applicable to 2-lane highways only and are reported by region with a comment, that for resurfacing only, differences among regions reflect differences in construction standards. Costs include engineering, materials and sundry estimated as 25% for resurfacing and grading and 30% for resurfacing only.

Region	Cost/km ($1000)	
	Resurfacing only	Resurfacing & Grading
S.West	120	215
Central	150	–
Eastern	110	250
Northern	65	155
N.West	110	150
Provincial	110	190

Appendix C/ User Information for Computer Software

C1/ Net marginal benefit method: Programs "ALLOC" and "ALLOCEXT"

Program ALLOC:

This is to be used for cases such as that illustrated in example 1 of Chapter 3. In such cases, different treatments are considered, each for a distinct group of sites for which the distribution of target accidents is known.

A sample input file, ALLOC.DAT, which was used for numerical example 1 in Chapter 3, is supplied on diskette and reproduced below. *Note that the first two lines of this file contain labelling information.*

A	1	2	3	4	5	6	7	8	9
1	Treatment 1	200	10	15	0.300	1.0490	5.9830	0.10	0.30
2	Treatment 2	300	5	10	0.200	2.0500	3.9010	0.20	0.20

Field descriptions are as follows:

A — Treatment unit number

1 — Description of treatment unit

2 — Number of sites

3 — Cost of treating one site

4 — Design life (years)

5 — Ratio of injury to total accidents

6* — Mean number of total accidents, μ

7* — Variance of total accidents, s^2

8 — Expected reduction in probability of severe accidents

9 — Expected reduction in probability of other accidents

* *If only the parameters α and β of the gamma distribution are given, then μ and s^2 could be estimated using equations 4 and 5 of chapter 3 as follows:*

$$\mu = \beta / \alpha$$

$$s^2 = \beta(1+\alpha)/\alpha^2$$

For a desired application, an input file of the above form would first be created. Other information would be input in response to screen prompts. These are:

- Name of input file
- Name of output file
- Discount rate
- Net annual benefit threshold

To use the program, the user simply types "ALLOC". The program does a trial-and-error convergence to find a net annual benefit threshold that makes the sum of the allocations equal to the available budget. Each run provides an allocation and total budget for a single threshold. At the end of a run the program allows a number of options:

a) Quit

b) Do another run with a new threshold

c) Write the results to the output file and quit

d) Write the results to the output file and do another run.

Program ALLOCEXT

This is to be used for cases such as that illustrated in example 2 of Chapter 3. In such cases, the best treatment for each site is known, and uncertainty in the target accident distribution for a site is expressed by a probability distribution whose parameters are known. The program can be used to determine the number of sites for each treatment type that could be accommodated within a given budget.

A sample input file, ALLOCEXT.DAT, which was used for numerical example 2 in Chapter 3, is supplied on diskette and reproduced below. *Note again that the first two lines of this file contain labelling information.* Basically the data structure is the same as for ALLOC.DAT except that treatments are specified by an integer in part of field 1 (the remainder of field 1 is blank).

A	1	Blank	2	3	4	5	6	7	8	9
1	1		1	10	15	0.400	2.9901	6.0400	0.10	0.30
2	1		1	10	15	0.360	1.3226	6.1223	0.10	0.30
3	1		1	10	15	0.30	0.5270	1.9431	0.10	0.30
4	1		1	10	15	0.36	0.1199	0.1584	0.10	0.30
5	1		1	10	15	0.3	0.2972	0.49	0.10	0.30
6	1		1	10	15	0.2	0.59	1.22	0.10	0.30
7	1		1	10	15	0.4	0.69	1.1	0.10	0.30
8	1		1	10	15	0.25	1.55	4.5	0.10	0.30
9	1		1	10	15	0.5	1.20	5.2	0.10	0.30
10	1		1	10	15	0.3	0.39	0.9	0.10	0.30
11	2		1	5	10	0.3	0.49	0.99	0.20	0.20
12	2		1	5	10	0.35	1.22	2.39	0.20	0.20
13	2		1	5	10	0.35	1.44	4.02	0.20	0.20
14	2		1	5	10	0.4	0.66	2.22	0.20	0.20
15	2		1	5	10	0.25	0.88	2.36	0.20	0.20
16	2		1	5	10	0.25	1.49	2.43	0.20	0.20
17	2		1	5	10	0.34	1.89	6.99	0.20	0.20
18	2		1	5	10	0.3	3.22	9.01	0.20	0.20
19	2		1	5	10	0.24	0.97	9.91	0.20	0.20
20	2		1	5	10	0.3	1.07	5.22	0.20	0.20

A	1	Blank	2	3	4	5	6	7	8	9
21	2		1	5	10	0.2	1.69	3.22	0.20	0.20
22	2		1	5	10	0.5	0.33	0.88	0.20	0.20
23	2		1	5	10	0.2	0.49	1.01	0.20	0.20
24	2		1	5	10	0.28	0.77	3.22	0.20	0.20
25	2		1	5	10	0.36	1.18	7.11	0.20	0.20

The creation of data files and operation of the program are the same as for ALLOC. To run the program, simply type "ALLOCEXT" and follow instructions.

The new version of the program is available and it is a menu-driven, user-friendly system.

C2/ Multi-Criteria Model

a) Sample Inputs

For the illustration in Chapter 3, we initially considered 16 accident types on 7 classes of roads — a total of 112 mutually exclusive cells. This was reduced to 66 cells after we found that there were few or no accidents in many cells. For demonstration, we chose 6 measures and each measure was subjectively rated in accordance with a four-point scale for its cost-effectiveness for each of the 66 cells. For 1 km sections in the province, the mean annual number of accidents/section and variance are provided in a separate table.

Four-point scale:

1. Top priority
2. Medium priority
3. Low priority
4. Not relevant/applicable

Measures

(For the demonstration these are, by necessity, broadly defined since the accident categorization is relatively broad.)

1. Roadway illumination
2. Shoulder widening/upgrading
3. Shoulder guiderail/sideslope flattening
4. Horizontal curve improvements
5. Median improvements
6. Removal/protection of roadside obstacles

Six road classes are considered in the tables below, and 16 types of accident are defined. An abbreviated notation is employed to identify specific occurrences. For example 7U2A means accident type 7 occurred on an urban primary road on a section having two lanes (A). The A and B symbols represent two sub-classes of road:

A = 2-lane sections;

B = multi-lane sections.

Cell numbers for accident / road classes

	Urban			Rural			
	Class 2		Class 3	Class 1	Class 2		Class 3
	2-lane	multi-lane			2-lane	multi-lane	
Day-curved-sv-severe	1U2A	1U2B		1R1	1R2A	1R2B	1R3
Day-curved-sv-PDO				2R1	2R2A		
Day-curved-mv-severe	3U2A	3U2B		3R1	3R2A	3R2B	3R3
Day-curved-mv-PDO				4R1	4R2A		
Day-strght-sv-severe	5U2A	5U2B	5U3	5R1	5R2A	5R2B	5R3
Day-strght-sv-PDO		6U2B		6R1	6R2A		
Day-strght-mv-severe	7U2A		7U3	7R1	7R2A	7R2B	7R3
Day-strght-mv-PDO				8R1	8R2A	8R2B	
Ngt-curved-sv-severe	9U2A	9U2B		9R1	9R2A	9R2B	9R3
Ngt-curved-sv-PDO				10R1	10RV		
Ngt-curved-mv-severe		11U2B		11R1	11R2A		11R3
Ngt-curved-mv-PDO				12R1	12R2A		
Ngt-strght-sv-severe	13U2A	13U2B	13U3	13R1	13R2A	13R2B	13R3
Ngt-strght-sv-PDO				14R1	14R2A		
Ngt-strght-mv-severe	15U2A	15U2B		15R1	15R2A	15R2B	15R3
Ngt-strght-mv-PDO				16R1	16R2A		

Legend

sv(mv) – single(multi) vehicle

PDO – property damage only

severe – injury+fatal

ngt – nighttime

Class 1 – Freeways

Class 2 – Primary roads

Class 3 – Secondary roads

Cell #	Ranking for measure #					
	1	2	3	4	5	6
1U2A	4	2	2	1	4	3
1U2B	4	3	3	1	2	3
1R1	4	3	2	1	2	2
1R2A	4	1	1	1	4	2
1R2B	4	2	2	1	3	3
1R3	4	1	1	1	4	3
2R1	4	3	3	2	3	3
2R2A	4	2	2	2	4	3
3U2A	4	2	3	2	4	4
3U2B	4	3	3	2	3	4
3R1	4	3	3	2	3	4
3R2A	4	2	3	2	4	4
3R2B	4	3	3	2	3	4
3R3	4	2	3	2	4	4
4R1	4	3	3	2	3	4
4R2A	4	3	3	2	4	4
5U2A	4	3	3	4	4	3
5U2B	4	3	3	4	2	3
5U3	4	3	3	4	4	3
5R1	4	3	3	4	2	2
5R2A	4	2	2	4	4	2
5R2B	4	3	3	4	3	3
5R3	4	2	2	4	4	3
6U2B	4	3	3	4	3	3
6R1	4	3	3	4	3	3
6R2A	4	3	3	4	4	3
7U2A	4	2	3	4	4	4
7U3	4	2	3	4	4	4
7R1	4	3	3	4	3	4
7R2A	4	2	3	4	4	4
7R2B	4	3	3	4	3	4
7R3	4	2	3	4	4	4
8R1	4	3	3	4	3	4
8R2A	4	3	3	4	4	4
8R2B	4	3	3	4	3	4

Cell #	Ranking for measure #					
	1	2	3	4	5	6
9U2A	3	2	2	1	4	3
9U2B	3	3	3	1	2	3
9R1	3	3	2	1	2	2
9R2A	1	2	2	2	4	2
9R2B	2	2	2	1	3	3
9R3	1	2	2	2	4	3
10R1	3	3	3	2	3	3
10R2A	1	2	2	2	4	3
11U2B	3	3	3	2	3	4
11R1	3	3	3	2	3	4
11R2A	2	2	3	1	4	4
11R2B	3	3	3	2	3	4
11R3	2	2	3	1	4	4
12R1	3	3	3	2	3	4
12R2A	2	3	3	1	4	4
13U2A	3	1	3	4	4	4
13U2B	3	2	3	4	3	4
13U3	3	1	3	4	4	4
13R1	3	2	3	4	3	4
13R2A	2	1	3	4	4	4
13R2B	3	2	3	4	3	4
13R3	2	1	3	4	4	4
14R1	3	3	3	4	3	4
14R2A	3	2	3	4	4	4
15U2A	2	2	3	4	4	4
15U2B	3	3	3	4	3	4
15U3	2	2	3	4	4	4
15R1	3	3	3	4	3	4
15R2A	2	2	3	4	4	4
15R2B	3	3	3	4	3	4
15R3	2	2	3	4	4	4
16R1	3	3	3	4	3	4
16R2A	3	3	3	4	4	4

Cell #	# of 1 km Sections	Accs/km/ year (89)	Standard Deviation	C.V.
1 U2A	157	0.179	0.517	0.347
3 U2A	157	0.316	0.842	0.375
5 U2A	157	0.940	1.711	0.550
7 U2A	157	2.484	3.312	0.750
9 U2A	157	0.302	0.885	0.341
13 U2A	157	0.546	0.949	0.575
15 U2A	157	0.488	0.893	0.547
1 U2B	141	0.480	2.406	0.199
3 U2B	141	1.015	1.871	0.543
5 U2B	141	2.590	2.828	0.916
6 U2B	141	0.264	0.706	0.374
9 U2B	141	0.424	1.863	0.227
11 U2B	141	0.184	0.731	0.252
13 U2B	141	1.910	2.661	0.718
15 U2B	141	4.780	5.710	0.837
5 U3	274	0.128	0.417	0.306
7 U3	274	0.148	0.843	0.176
13 U3	274	0.099	0.419	0.236
1 R1	1956	1.300	3.937	0.330
2 R1	1956	0.043	0.306	0.141
3 R1	1956	0.888	4.192	0.212
4 R1	1956	0.005	0.095	0.048
5 R1	1956	4.561	8.328	0.548
6 R1	1956	0.119	0.468	0.255
7 R1	1949	5.501	13.988	0.393
8 R1	1956	0.046	0.298	0.155
9 R1	1956	0.902	3.549	0.254
10 R1	1956	0.026	0.239	0.108
11 R1	1956	0.369	1.783	0.207
12 R1	1956	0.009	0.150	0.057
13 R1	1956	3.295	5.968	0.552
14 R1	1956	0.103	0.441	0.232
15 R1	1956	2.263	6.608	0.342
16 R1	1956	0.039	0.286	0.137
1 R2A	13157	0.159	0.649	0.244

Cell #	# of 1 km Sections	Accs/km/ year (89)	Standard Deviation	C.V.
2 R2A	13157	0.009	0.115	0.076
3 R2A	13157	0.078	0.436	0.179
4 R2A	13157	0.004	0.073	0.051
5 R2A	13157	0.436	1.075	0.405
6 R2A	13157	0.017	0.162	0.108
7 R2A	13157	0.613	2.019	0.304
8 R2A	13157	0.019	0.180	0.108
9 R2A	13157	0.110	0.472	0.232
10 R2A	13157	0.008	0.116	0.072
11 R2A	13157	0.020	0.204	0.096
12 R2A	13157	0.001	0.028	0.025
13 R2A	13157	0.337	0.883	0.382
14 R2A	13157	0.011	0.130	0.086
15 R2A	13157	0.126	0.570	0.220
16 R2A	13157	0.008	0.114	0.066
1 R2B	450	0.406	1.232	0.329
3 R2B	450	0.281	0.939	0.299
5 R2B	450	2.024	2.577	0.785
7 R2B	450	5.825	11.282	0.516
8 R2B	450	0.120	0.489	0.246
9 R2B	450	0.278	1.119	0.248
13 R2B	450	1.340	1.925	0.696
15 R2B	450	1.633	3.950	0.413
1 R3	5435	0.061	0.336	0.181
3 R3	5435	0.015	0.170	0.086
5 R3	5435	0.062	0.331	0.187
7 R3	5435	0.032	0.250	0.127
9 R3	5435	0.037	0.244	0.153
11 R3	5435	0.005	0.099	0.054
13 R3	5435	0.051	0.305	0.168
15 R3	5435	0.004	0.085	0.051

Results of MARS Runs

In analyzing the data for the seven classes of roads (one class had no data), four different approaches were taken in prioritizing the criteria (accident types):

Approach 1 – Prioritize the criteria using average number of accidents @ km (μ).

Approach 2 – Prioritize by standard deviation in number of accidents @ km (σ).

Approach 3 – Prioritize by the product of μ and σ, i.e., $\pi = \mu \times \sigma$.

Approach 4 – Use the ordinal version of π (e.g., if $\pi_1 = 3.5$, $\pi_2 = 2.7$, $\pi_3 = 4.6$, call accident type 1 a rank of 2, type 2 a rank of 1, and type 3 a rank of 3).

We refer to Approaches 1, 2, and 3 as using numerical weights (actual numerical data), and Approach 4 as using ordinal weights.

Because the relative sizes of the σ-values seem to go in the same direction as the μ-values, (i.e., if μ is large, σ is large; if μ is small, σ is small), all four approaches gave approximately the same outcome.

The following table displays the ranking of the six measures for each of the seven road classes and the four approaches.

Rankings of safety measures

Road Class	Approach 1	Approach 2	Approach 3	Approach 4
U2A	M2=100.0	M2=100.0	M2=100.0	M2=100.0
	M3=77.8	M3=79.2	M3=77.3	M3=77.8
	M4=59.9	M4=66.8	M6=54.9	M4=63.2
	M1=57.9	M1=58.5	M4=54.2	M1=62.2
	M6=55.9	M6=57.0	M1=54.1	M6=56.5
	M5=48.7	M5=47.7	M5=50.4	M5=46.8
U2B	M5=100.0	M4=100.0	M5=100.0	M5=100.0
	M2=100.0	M5=100.0	M2=100.0	M2=948.3
	M3=89.7	M2=100.0	M3=92.8	M4=94.5
	M4=85.4	M3=86.8	M1=84.5	M3=88.1
	M1=76.9	M1=72.3	M4=73.2	M1=72.3
	M6=66.2	M6=66.3	M6=65.7	M6=69.3
U3	M2=100.0	M2=100.0	M2=100.0	M2=100.0
	M3=71.1	M3=69.2	M2=70.5	M3=78.0
	M6=50.3	M6=46.1	M3=46.8	M6=60.3
	M1=47.6	M1=46.1	M1=45.3	M1=55.9
	M4=39.5	M4=38.5	M4=39.4	M4=51.5
	M5=39.5	M5=38.5	M6=39.4	M5=51.5
R1	M5=100.0	M4=100.0	M5=100.0	M5=100.0
	M2=100.0	M5=100.0	M2=100.0	M2=97.9
	M3=92.7	M2=100.0	M3=92.9	M3=96.5
	M4=86.7	M3=94.8	M6=78.4	M4=94.3
	M6=80.0	M6=78.6	M4=73.2	M6=76.0
	M1=69.3	M1=70.1	M1=68.4	M1=70.4
R2A	M2=100.0	M2=100.0	M2=100.0	M2=100.0
	M3=80.8	M3=82.1	M3=79.8	M3=84.7
	M6=63.8	M4=647.9	M6=61.6	M4=69.9
	M1=62.3	M1=65.7	M1=57.8	M1=66.6
	M4=57.9	M6=63.1	M4=53.5	M6=60.8
	M5=45.7	M5=46.6	M5=48.7	M5=42.8
R2B	M2=100.0	M2=100.0	M2=100.0	M2=100.0
	M3=96.6	M3=97.5	M3=99.0	M3=95.9
	M5=94.9	M5=94.4	M5=98.7	M5=90.2
	M4=77.6	M4=85.9	M1=77.3	M4=78.6
	M1=73.6	M1=74.3	M6=70.9	M1=69.4
	M6=71.5	M6=70.1	M4=70.6	M6=65.1
R3	M2=100.0	M2=100.0	M2=100.0	M2=100.0
	M3=85.3	M3=83.1	M3=90.2	M3=85.1
	M4=65.5	M4=72.5	M4=65.6	M4=70.2
	M1=58.2	M1=62.8	M6=55.7	M1=65.5
	M6=54.1	M6=52.6	M1=45.9	M6=53.3
	M5=38.3	M5=39.5	M5=36.1	M5=39.8

The overall results (using, say, Approach 4) are:

Class	*Recommended Measure*
U1	–
U2A	M2
U2B	M5 preferred, M2, M4 close seconds
U3	M2
R1	M5 preferred, M2, M3 close seconds
R2A	M2
R2B	M2 preferred, M3, M5 close seconds
R3	M2

b) Instructions for use of software

A separate manual for using multi-criteria software is in progress.

c) Technical aspects of the multi-criteria model

The attached paper provides background information on the theoretical aspects of the multi-criteria model.

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